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M01-04-0622

Work Plan For A Treatability Study In Support Of The Intrinsic Remediation (Natural Attenuation) Option For North And South Gas Stations



**Travis Air Force Base,
California**

Prepared for

**Air Force Center For Environmental Excellence
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Brooks Air Force Base
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August 1995

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TABLE OF CONTENTS

	<u>Page</u>
SECTION 1 INTRODUCTION.....	1-1
1.1 SCOPE OF CURRENT WORK PLAN.....	1-2
1.2 BACKGROUND.....	1-3
SECTION 2 DATA REVIEW AND CONCEPTUAL MODEL DEVELOPMENT ..	2-1
2.1 DATA REVIEW	2-1
2.1.1 Topography, Surface Hydrology, and Climate.....	2-1
2.1.2 Overview of Geology and Hydrogeology	2-2
2.1.2.1 Regional Geology and Hydrogeology	2-2
2.1.2.2 Site Geology and Hydrogeology.....	2-5
2.1.3 Soil Quality.....	2-11
2.1.4 Groundwater Quality and Chemistry.....	2-17
2.2 DEVELOPMENT OF CONCEPTUAL MODEL.....	2-17
2.2.1 Intrinsic Remediation and the Bioplume II Model.....	2-22
2.2.2 Biodegradation of Dissolved BTEX Contamination.....	2-23
2.2.3 Initial Conceptual Model.....	2-24
2.2.4 Potential Pathways and Receptors.....	2-25
SECTION 3 COLLECTION OF ADDITIONAL DATA	3-1
3.1 MONITORING POINT INSTALLATION	3-3
3.1.1 Monitoring Point Locations and Completion Intervals.....	3-3
3.1.2 Monitoring Point Installation Procedures.....	3-5
3.1.2.1 Pre-Placement Activities.....	3-5
3.1.2.2 Geoprobe Direct Push Technology	3-6
3.1.2.3 Equipment and Monitoring Point Materials Decontamination.....	3-9
3.1.2.4 Installation and Materials.....	3-9
3.1.2.4.1 Deep Monitoring Points	3-11
3.1.2.4.2 Shallow Monitoring Points.....	3-11
3.1.2.5 Monitoring Point Completion.....	3-12
3.1.2.6 Monitoring Point Abandonment and Site Restoration.....	3-12
3.1.2.7 Monitoring Point Development and Records	3-13
3.1.3 Groundwater Grab Sampling Procedures.....	3-13
3.1.4 Monitoring Point Location and Datum Survey	3-15
3.1.5 Water Level Measurements	3-15
3.2 GROUNDWATER SAMPLING	3-15
3.2.1 Preparation for Sampling.....	3-16
3.2.1.1 Equipment Cleaning.....	3-16
3.2.1.2 Equipment Calibration	3-17

TABLE OF CONTENTS (continued)

	<u>Page</u>
3.2.2 Sampling Procedures.....	3-17
3.2.2.1 Preparation of Location.....	3-20
3.2.2.2 Water Level and Total Depth Measurements	3-20
3.2.2.3 Monitoring Well/Point Purging	3-20
3.2.2.4 Sample Extraction.....	3-20
3.2.3 Onsite Groundwater Parameter Measurement.....	3-21
3.2.3.1 Dissolved Oxygen Measurements.....	3-21
3.2.3.2 pH, Temperature, and Specific Conductance.....	3-21
3.2.3.3 Alkalinity Measurements	3-22
3.2.3.4 Nitrate- and Nitrite-Nitrogen Measurements	3-22
3.2.3.5 Carbon Dioxide Measurements.....	3-22
3.2.3.6 Sulfate and Sulfide Sulfur Measurements.....	3-23
3.2.3.7 Total Iron, Ferrous Iron, and Ferric Iron Measurements	3-23
3.2.3.8 Manganese Measurements	3-23
3.2.3.9 Redox Potential.....	3-23
3.3 SAMPLE HANDLING FOR LABORATORY ANALYSIS	3-24
3.3.1 Sample Preservation	3-24
3.3.2 Sample Container and Labels.....	3-24
3.3.3 Sample Shipment.....	3-25
3.3.4 Chain-of-Custody Control.....	3-25
3.3.5 Sampling Records.....	3-26
3.3.6 Laboratory Analyses.....	3-26
SECTION 4 REMEDIAL OPTION EVALUATION AND TS REPORT	4-1
SECTION 5 QUALITY ASSURANCE/QUALITY CONTROL	5-1
SECTION 6 PROJECT SCHEDULE.....	6-1
SECTION 7 REFERENCES.....	7-1
 APPENDIX A	 Containers, Preservatives, Packaging and Shipping Requirements for Groundwater Samples
APPENDIX B	Soil and Groundwater Analytical Results from Stage 1 Investigation
APPENDIX C	Well Construction Summary and Soil Boring Logs From Previous Investigations
APPENDIX D	Preliminary Evaluation of Intrinsic Remediation from Previous Investigations

LIST OF FIGURES

<u>Figure</u>		<u>Page</u>
1.1	Regional Location Map	1-4
1.2	Site Map.....	1-5
2.1	Geologic Map	2-3
2.2	Geologic Cross-Section	2-4
2.3	Soil Map	2-6
2.4	Basewide Groundwater Elevation Contours February 1995	2-7
2.5	Location of Soil Borings, Monitoring and Extraction Wells, and Geologic Cross Section	2-8
2.6	Geologic Cross Section A-A'.....	2-9
2.7	Geologic Cross Section B-B'	2-10
2.8	Groundwater Elevation Contours - December 1994	2-12
2.9	TPH (Gasoline) Concentrations in Groundwater - July and December 1994	2-20
2.10	Benzene Concentrations in Groundwater - July and December 1994	2-21
3.1	Proposed Geoprobe Sampling and/or Monitoring Point Locations	3-4
3.2	Cross Section of GeoProbe.....	3-7
3.3	Geologic Boring Log	3-8
3.4	Monitoring Point Installation Record.....	3-10
3.5	Monitoring Point Development Records.....	3-14
3.6	Groundwater Sampling Record	3-18

LIST OF TABLES

<u>Table</u>	<u>Page</u>
2.1 Hydraulic Testing Results	2-13
2.2 Soil Contaminant Concentrations of Organic and Fuel Fraction Analytes	2-14
2.3 Soil Concentrations of Fuel Additives and Inorganic Parameters.....	2-15
2.4 Soil Contaminant Concentrations (Second Round).....	2-16
2.5 Groundwater Contaminant Concentrations of Organic and Fuel Fraction Analytes	2-18
2.6 Groundwater Contaminant Concentrations (Second Round).....	2-19
3.1 Analytical Protocol for Groundwater Samples.....	3-2
4.1 Example TS Report Outline	4-2
5.1 QA/QC Sampling Program.....	5-2

SECTION 1

INTRODUCTION

This work plan, prepared by Parsons Engineering Science, Inc. (Parsons ES) [formerly Engineering-Science, Inc. (ES)], presents the scope of work required for the collection of data necessary to conduct a treatability study (TS) for remediation of groundwater contaminated with petroleum hydrocarbons at the North and South Gas Stations (NSGS), Travis Air Force Base (AFB), California. Hydrogeologic and groundwater chemical data necessary to evaluate multiple remedial options will be collected under this program; however, this work plan is primarily oriented toward the collection of hydrogeologic data to be used in support of intrinsic remediation (natural attenuation) for restoration of fuel-hydrocarbon-contaminated groundwater. Other remedial options will be considered in conjunction with intrinsic remediation during the TS, including free product removal; groundwater extraction and treatment (i.e., pump and treat); biosparging; bioslurping; and natural contaminant attenuation (intrinsic remediation) with long-term monitoring.

Data collected during the TS will also be used as input into the Bioplume II groundwater solute transport model code. As part of the TS, the Bioplume II modeling effort has three primary objectives: 1) to predict the future extent and concentration of the dissolved contaminant plume by modeling the effects of advection, dispersion, sorption, and biodegradation; 2) to assess the possible risk to potential downgradient receptors; and 3) to provide technical support for selection of the intrinsic remediation option as the best remedial alternative at regulatory negotiations, as appropriate. The TS and the Bioplume II modeling effort for the NSGS site will involve completion of several tasks, which are described in the following sections.

This work plan was developed based on discussions among representatives from the Air Force Center for Environmental Excellence (AFCEE) Technology Transfer Division, Travis AFB, Parsons ES, and the California Regional Water Quality Control Board (RWQCB) at a meeting at the Base on May 18, 1995; on the statement of work (SOW) for this project; and on a review of existing site characterization data. All field work will follow the health and safety procedures presented in the program *Health and Safety Plan for Bioplume II Modeling Initiative* (ES, 1993) and the site-specific addendum to the program Health and Safety Plan.

1.1 SCOPE OF CURRENT WORK PLAN

The ultimate objective of the work described herein is to provide a TS for remediation of groundwater contamination at the NSGS site. However, this project is part of a larger, broad-based initiative being conducted by AFCEE in conjunction with the US Environmental Protection Agency (USEPA) and Parsons ES to document the biodegradation and resulting attenuation of fuel hydrocarbons and solvents dissolved in groundwater, and to model this degradation using the Bioplume II numerical groundwater model. For this reason, the work described in this work plan is directed toward the collection of data in support of this initiative. All data required to develop a 30-percent design of an alternate remediation system, should intrinsic remediation not prove to be a viable remedial option at this facility, also will be collected under this program.

Field activities will be performed to determine the extent of residual, mobile, and dissolved contamination at the NSGS site. These data will be used along with data from previous investigations to complete the characterization of contaminants at the site and for use in the Bioplume II model to predict the future concentrations and extent of contamination.

This work plan describes the site characterization activities to be performed in support of the TS and the Bioplume II modeling effort. Site characterization activities in support of the TS include: 1) determination of preferential contaminant migration pathways; 2) lithographic soil sampling using the Geoprobe® apparatus; 3) groundwater monitoring point placement; and 4) groundwater sampling. The materials and methodologies required for collection of these data are described herein. Where appropriate, data generated during previous site characterization activities will be used to save costs and avoid duplication of previous efforts. Existing site-specific data and data collected during the supplemental site characterization activities described in this work plan will be used as input for the Bioplume II model. Where site-specific data are not available, conservative values for the types of aquifer materials present at the site obtained from widely accepted published literature will be used for model input. Sensitivity analyses will be conducted for the parameters which are known to have the greatest influence on the results of Bioplume II modeling, and where possible, the model will be calibrated using historical site data.

Upon completion of the Bioplume II modeling, Parsons ES will provide technical assistance at regulatory negotiations to support the intrinsic remediation option if the results of the modeling indicate that this approach is warranted. If it is shown that intrinsic remediation is not the most appropriate remedial option, Parsons ES will recommend the most appropriate groundwater remedial technology based on available data.

This work plan consists of six sections, including this introduction. Section 2 presents a review of existing site-specific data and a conceptual model for the site. Section 3 describes the proposed sampling strategy and procedures to be used for the collection of additional site characterization data. Section 4 describes the remedial option evaluation procedure and TS report format. Section 5 describes the quality assurance/quality control (QA/QC) measures to be used during this project. Section 6 contains the proposed schedule of activities and milestones. Section 7 contains the references used in preparing this document. There are four appendices to this work plan. Appendix A contains a listing of containers, preservatives, packaging, and shipping requirements for groundwater samples. Appendix B contains a summary of soil and groundwater analytical data from a Stage 1 Remedial Investigation (RI). Appendix C contains a well construction summary and soil boring logs from previous investigations. Appendix D contains data from a limited intrinsic remediation investigation which has already been performed at the NSGS site.

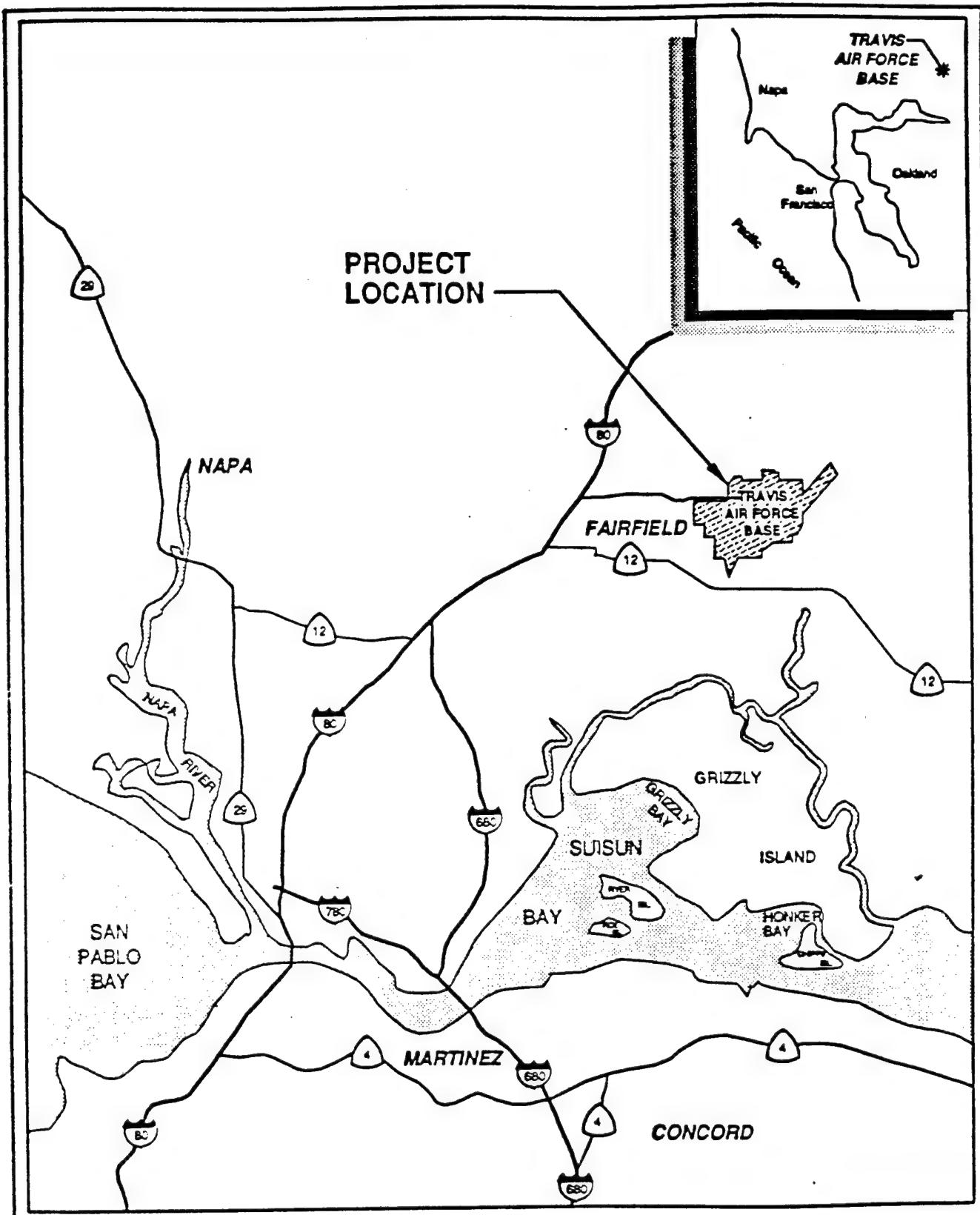
1.2 BACKGROUND

Travis AFB is located in Solano County, California, approximately 3 miles east of the town of Fairfield, midway between the cities of San Francisco and Sacramento. Figure 1.1 shows the location of Travis AFB. The Base occupies 5,025 acres of land in Solano County and has 17,000 military and non-military personnel on site on a daily basis. The land surrounding the base is used essentially for agriculture. The northeast portion of the base is directly bordered by irrigated croplands. Housing dormitories on the base were 95 percent occupied in 1991.

The project site consists of two base exchange gasoline service stations (Figure 1.2) which are referenced together as the NSGS site. Both stations are currently in use. The South Gas Station (SGS) (Building 170) is the larger of the two and is located on the southeastern corner of the intersection of Travis and Broadway Avenues. Land use on the base adjacent to the NSGS site consists of parking areas and buildings used for the base fire department and dormitories.

Fuel leaks from tanks and piping occurred at both gas stations. In 1988, an underground storage tank (UST) leak was discovered at the North Gas Station (NGS). Later in 1988, the contaminated soil was removed and tanks were replaced at the NGS. In the same year, a product inventory loss of 3,800 gallons of premium unleaded gasoline at the SGS led to discovery of a leaking distribution line to the southwestern pump island. The pipeline trench area between the tank pit and the southwestern pump island was excavated and the pipeline repaired.

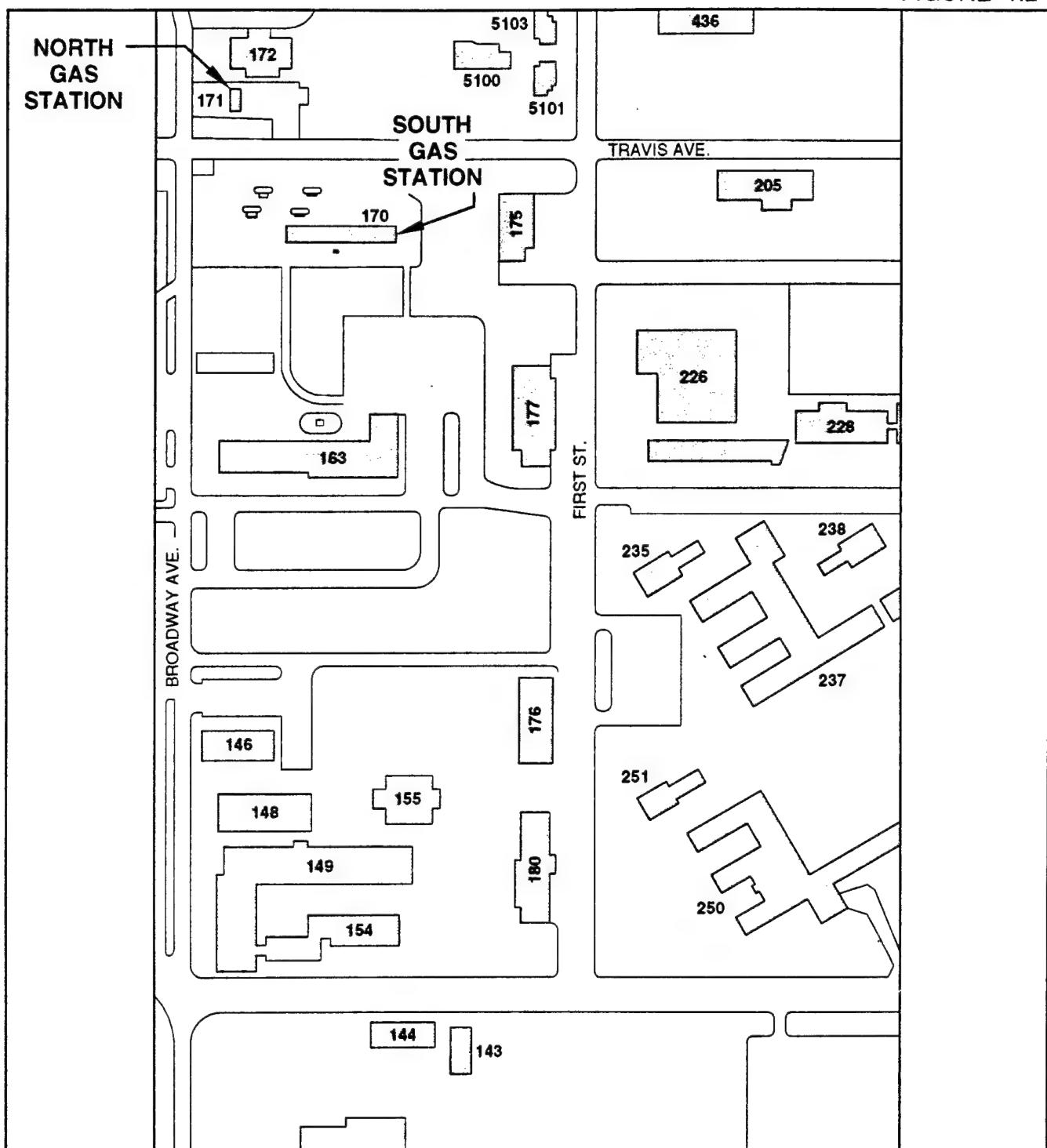
FIGURE 1.1



REGIONAL LOCATION MAP

TRAVIS AIR FORCE BASE, CALIFORNIA

FIGURE 1.2



A horizontal scale bar with tick marks at 0, 125, and 250. Below the bar, the text "SCALE IN FEET" is written in a bold, sans-serif font.

EXPLANATION

171

STRUCTURE



GAS PUMP ISLAND

SITE MAP

**NORTH AND SOUTH GAS STATIONS
TRAVIS AIR FORCE BASE, CALIFORNIA**

In 1989-1990, Roy F. Weston, Inc. conducted a Stage 1 Remedial Investigation/Feasibility Study (RI/FS) for the NSGS site. The investigations showed that gasoline contamination had spread outside the immediate SGS tank pit area and migrated to the shallow groundwater creating a plume of contamination. Free product was reported in two monitoring wells, one adjacent to each of the tank pits.

In 1994, Parsons ES conducted a Stage 2 remedial investigation (RI) for the NSGS site. The investigation showed that gasoline contamination in groundwater had spread southward from the NGS beneath Travis Avenue and merged with the SGS contamination. The gasoline plume from the SGS has moved southward as far as Building 163. Free product was reported in two monitoring wells, one downgradient of the NGS tank pit and one downgradient of the SGS tank pit. Six-inch extraction wells were installed adjacent to these two locations.

As part of the Stage 2 RI, a preliminary evaluation of intrinsic bioremediation was conducted. This preliminary evaluation indicated that the site groundwater has a high capacity to assimilate benzene, toluene, ethylbenzene, and xylenes (BTEX) and further study and modeling was recommended.

SECTION 2

DATA REVIEW AND CONCEPTUAL MODEL DEVELOPMENT

Site-specific data were reviewed and used to develop a conceptual model for groundwater flow and contaminant transport at the NSGS site. This conceptual model guided the development of sampling locations and analytical data requirements needed to support the Bioplume II modeling effort and to evaluate potential remediation technologies, including intrinsic remediation. Section 2.1 presents a synopsis of available site data. Section 2.2 presents the preliminary conceptual groundwater flow and contaminant transport model that was developed based on these data.

2.1 DATA REVIEW

The following sections are based upon review of data from the following sources:

- Stage 1 Draft Final RI/FS Report, North and South Gas Stations, Travis Air Force Base, California (Weston, 1991)
- Stage 2 Remedial Investigation Report, North and South Gas Stations, Travis Air Force Base, California (Parsons ES, 1995)

2.1.1 Topography, Surface Hydrology, and Climate

Travis AFB is located in a small structural basin known as the Suisun-Fairfield Basin. The Suisun-Fairfield Basin is separated from the southwestern Sacramento Valley by low hills extending northwest to southeast. These hills form the eastern boundary of the Suisun-Fairfield Basin. The Diablo Range and the Vacaville Mountains form the south and north-northwest boundaries, respectively. The western boundary is the Green Valley Fault.

Travis AFB is situated on a generally flat alluvial plain bound to the north and west by low hills. This alluvial plain slopes southward with a gradient of approximately 0.25 to 0.50 percent. Elevations in this region range from sea level at Suisun Bay south of the base to 1,300 feet above mean sea level (MSL) in the coast ranges north of the base. The south, east, and central portions of the base range from 40 to 70 feet above MSL, with the NSGS site at 61 to 66 feet elevation in the north central portion of the base.

Surface drainage at Travis AFB follows the general southward slope of the ground surface. However, due to erection of buildings on the Base surface drainage has been altered. The NSGS site is covered by asphalt with site surface drainage toward man-made catch basins.

Characteristic weather for the base consists of dry hot summers and cool moist winters, with an average annual temperature of 60 degrees Fahrenheit (°F). The base receives approximately 95 percent of the annual precipitation from October through May, the majority falling during the period December through February. Total average annual precipitation is approximately 16.1 inches per year. Evapotranspiration at the base occurs at a rate of 47 inches per year, yielding a net precipitation of -31 inches per year.

2.1.2 Overview of Geology and Hydrogeology

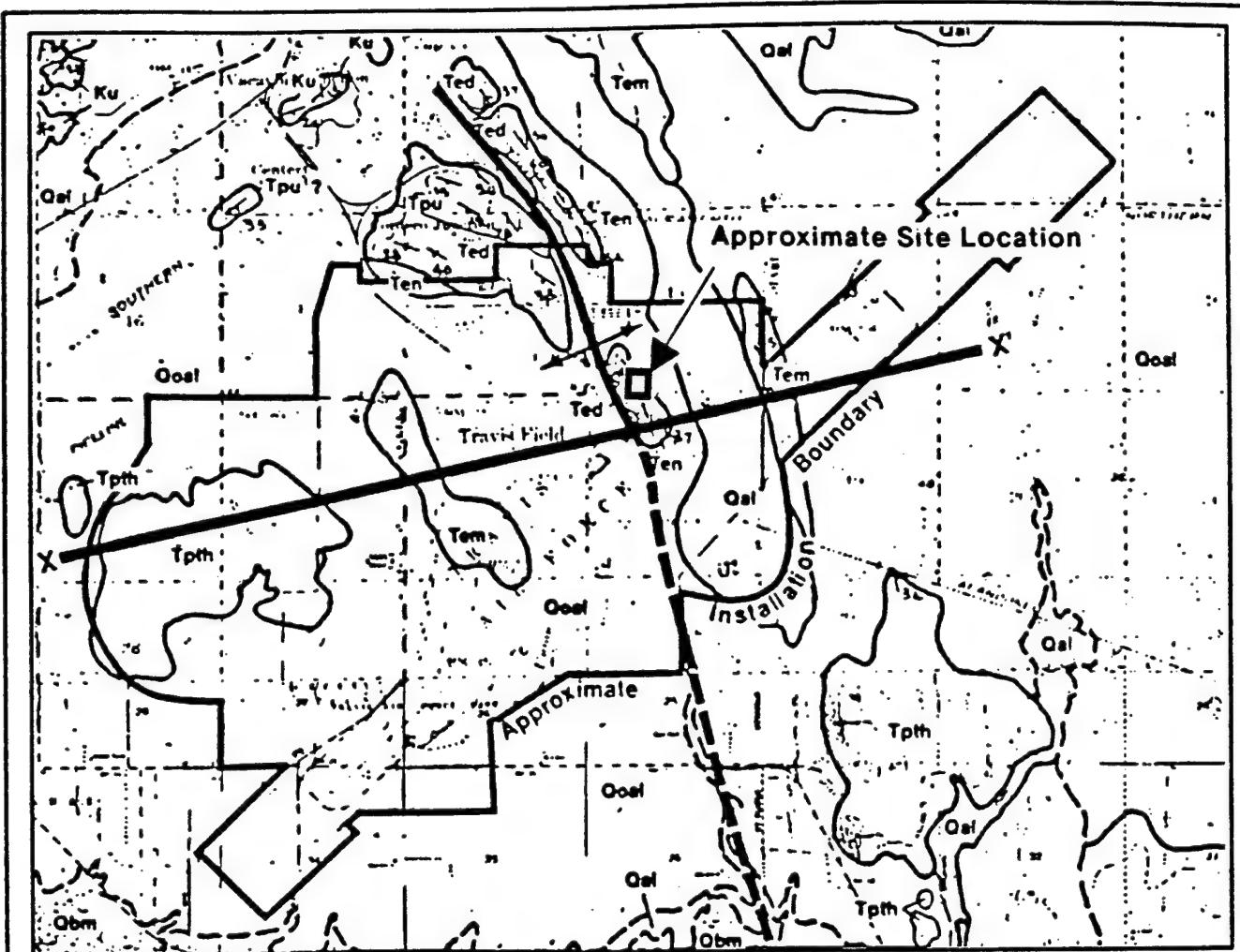
2.1.2.1 Regional Geology and Hydrogeology

The near-surface stratigraphy at the base is characterized by alluvial deposits of Tertiary and Recent age. These deposits, derived from rocks of the Coast Ranges, consist of interbedded, poorly stratified, and unconsolidated clay, silt, sand and gravel (Figure 2.1). Aggregate thicknesses range from a few feet to 50 feet. Sedimentary units in this area are usually lenticular and unconsolidated with low porosity and permeability. Beneath these beds are more consolidated beds of coarser grained Pleistocene and Pliocene continental clay, silt, sand, and gravel. The continental units lie on well-indurated Miocene to Paleocene sandstone, siltstone, and shale of marine origin. These units outcrop at several locations on the base and are described as fine-grained, dense units with low permeability and porosity. The weathered portions of the Tertiary units closely resemble the overlying alluvial deposits.

Travis AFB straddles the axis of a southeast plunging asymmetric anticline trending N35W, which is coincident with the Vaca-Kirby Hills Fault (Figure 2.2). Mapping of the fault suggests rotational movement resulting in the western side of the anticline plunging at a steeper angle than the east side of the fault. Hydrology on the base could be influenced by this and other related faults. The faults may act as barriers or conduits for groundwater.

The Quaternary alluvial deposits of clay, silt, and fine-grained sand overlying the Tertiary deposits are primary to understanding the regional and site hydrogeology. Groundwater occurs in lenses of coarser material within the Quaternary deposits. Recharge of the groundwater occurs through direct precipitation or from Denverton and Union Creeks, two north to south running streams. Aquifers in the area are unconfined with locally occurring confined and perched conditions. No groundwater is used on the Base. Groundwater usage off the Base in the vicinity is limited to small quantities which are used for domestic or stock purposes.

FIGURE 2.1



EXPLANATION

X-X'	TRACE OF CROSS SECTION	Ten	NORTONVILLE SHALE - SILTY CLAY SHALE, SILTSTONE, AND MINOR SANDSTONE INTERBEDS
Qbm	BAY MUD - SILTY AND CLAY, ABUNDANT ORGANIC MATTER, LOCAL SAND, GRAVEL, PEAT	Ted	DOMENGINE SANDSTONE - COARSE-GRAINED QUARTZ SANDSTONE
Qal	ALLUVIUM - COMPLEXLY INTERBEDDED CLAY, SILT, SAND, AND GRAVEL	Tpu	UNNAMED FORMATION - SILTY TO SANDY SHALE, THIN FRIABLE SANDSTONE INTERBEDS
Qoal	OLDER ALLUVIUM - COMPLEXLY INTERBEDDED CLAY, SILT, SAND, AND GRAVEL	Ku	CRETACEOUS UNDIFFERENTIATED - INTERBEDDED SHALE, SILTSTONE, AND SANDSTONE
Tph	TEHAMA FORMATION - COMPLEXLY INTERBEDDED GRAVEL, SAND, SILT, AND CLAY, OCCASSIONAL VOLCANICLASTICS, PARTLY CONSOLIDATED LOCALLY	↗ 35	STRIKE AND DIP OF BEDS SHOWING ANGLE OF DIP
Tem	MARKLEY SANDSTONE - MEDIUM TO COARSE-GRAINED MICACEOUS, FELDSPATHIC SANDSTONE		SURFACE TRACE OF VACA-KIRBY HILL FAULT; DASHED WHERE ASSUMED BENEATH ALLUVIAL COVER (BAILY, 1930); (STRAND AND KOENIG, 1965); ARROWS WHERE COINCIDENT WITH ANTICLINE AXIS

SOURCE: MODIFIED FROM ROY F. WESTON, INC., 1991



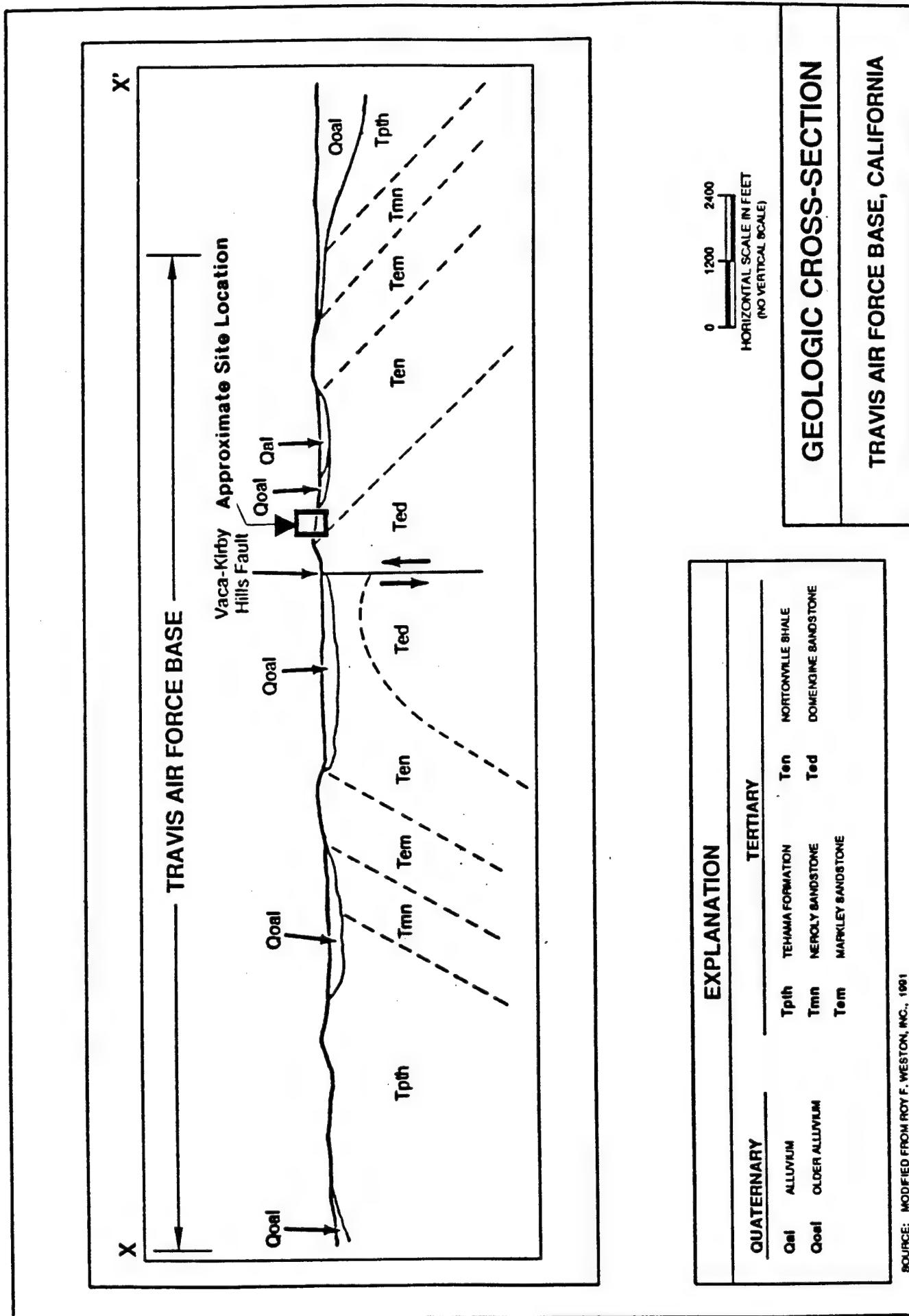
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SCALE IN FEET

GEOLOGIC MAP

TRAVIS AIR FORCE BASE, CALIFORNIA

PARSONS ENGINEERING SCIENCE, INC.

FIGURE 2.2



Travis AFB native soils primarily consist of silt and clay loams which exhibit minor sand, low permeability, and poor drainage. Specific soils at the base include Antioch, San Ysidro, Millsap, Solano, and Dibble-Los Osos soils. A soil map of Travis AFB is presented on Figure 2.3. The heterogeneous soils underlying Travis AFB produce considerable variability in aquifer characteristics derived from pump and gravity injection tests (Weston, 1991). Conductivity values range from 0.20 to 86.4 feet per day (ft/day) with a mean value of 21.5 ft/day across the base. Transmissivities vary from 3.83 to 883 square feet per day across the base.

Groundwater levels in the area are very responsive to precipitation and will increase during the principal rainy season, November through April. The aquifers usually experience a subsequent water level decline during the main dry season, May through October. The average fluctuation in water levels is 2 to 3.5 feet. General groundwater flow direction at the base is south toward Suisun Marsh and Suisun Bay (Figure 2.4).

2.1.2.2 Site Geology and Hydrogeology

Surficial sediments at the NSGS site consist of Quaternary alluvial deposits. Geologic cross-sections were developed from lithologic descriptions from the NSGS site (Figures 2.5 through 2.7). The cross-sections generally show a surficial clay across the site with a thickness of approximately 10 to 15 feet. This clay acts locally as an aquitard. Underlying the clay is fine to coarse grained sand and/or silt. Investigations indicated that these units were generally flat-lying and laterally continuous across the site. The maximum soil contamination was found at or near the interface between these two units indicating contamination which had migrated through groundwater. Lenses of sand within the upper clay and clay within the lower sand were occasionally present.

Across most of the NSGS site, bedrock consisting of weathered shale was found at depths of 25 to 40 feet below ground surface (bgs). In boreholes along Broadway Avenue the weathered bedrock surface was encountered 10 to 15 feet bgs. The probable identity of this unit is Nortonville Shale, which consists of silty clay shale, siltstone, and minor sandstone interbeds. The bedrock is expected to severely restrict the vertical movement of groundwater.

Groundwater at the site varied in depth from 9.0 to 14.2 feet bgs in July 1994, and from 7.9 to 14.1 feet bgs in December 1994. The potentiometric surface rose an average of 0.18 feet from July to December 1994 (average of 17 wells). The gradient calculated from water levels was approximately 0.002 toward the south-southeast. Groundwater appears to be

FIGURE 2.3

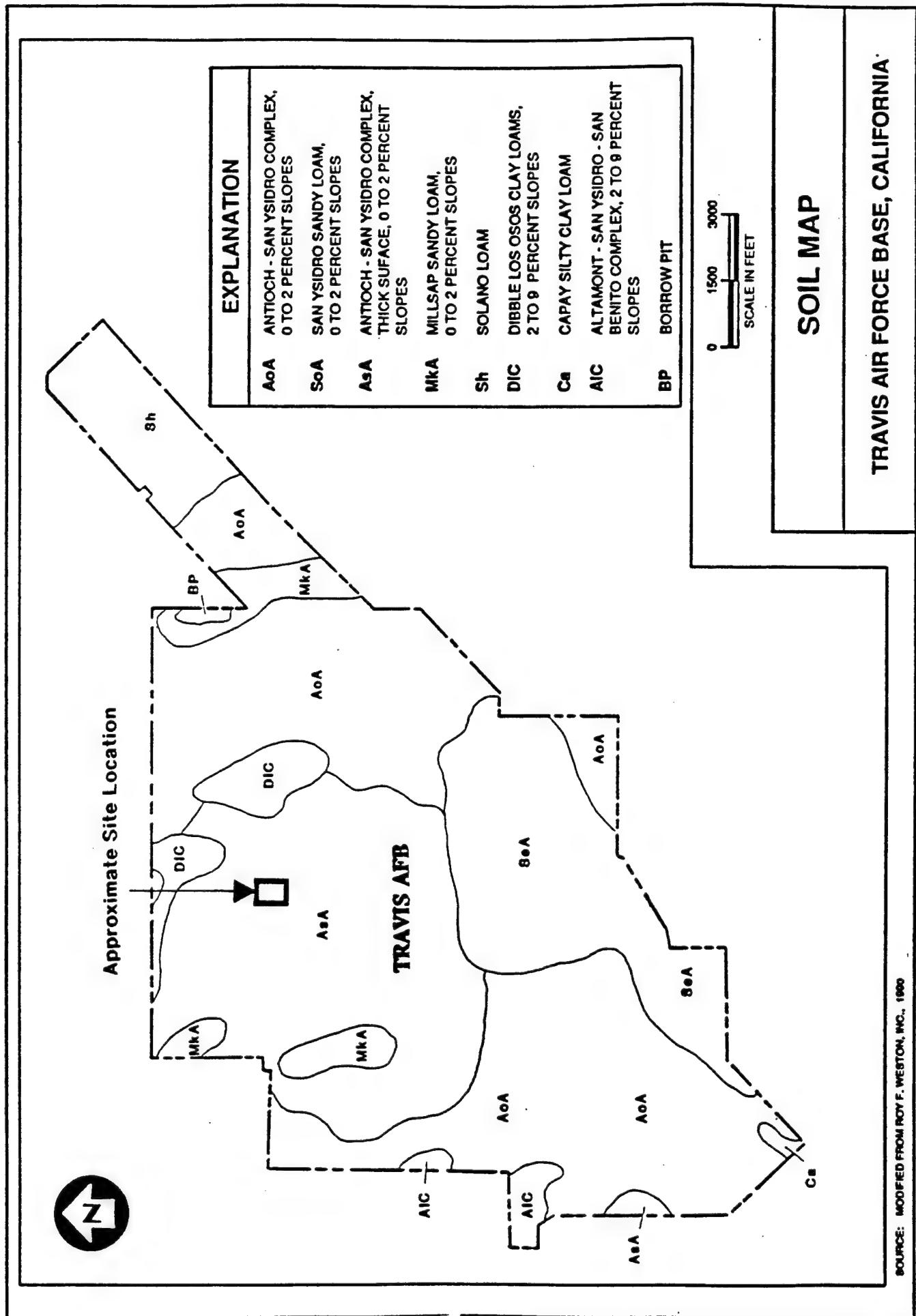


FIGURE 2.6

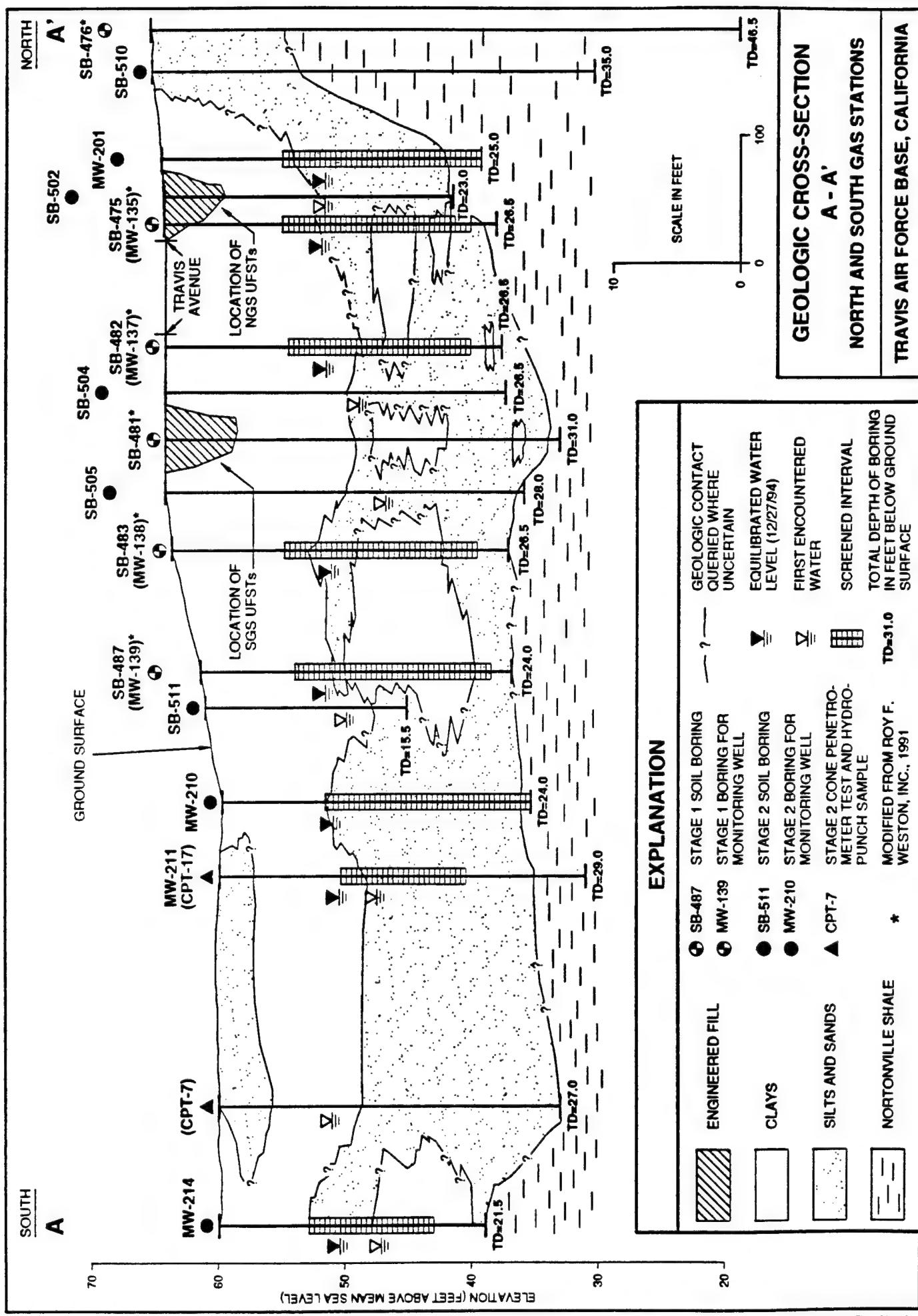
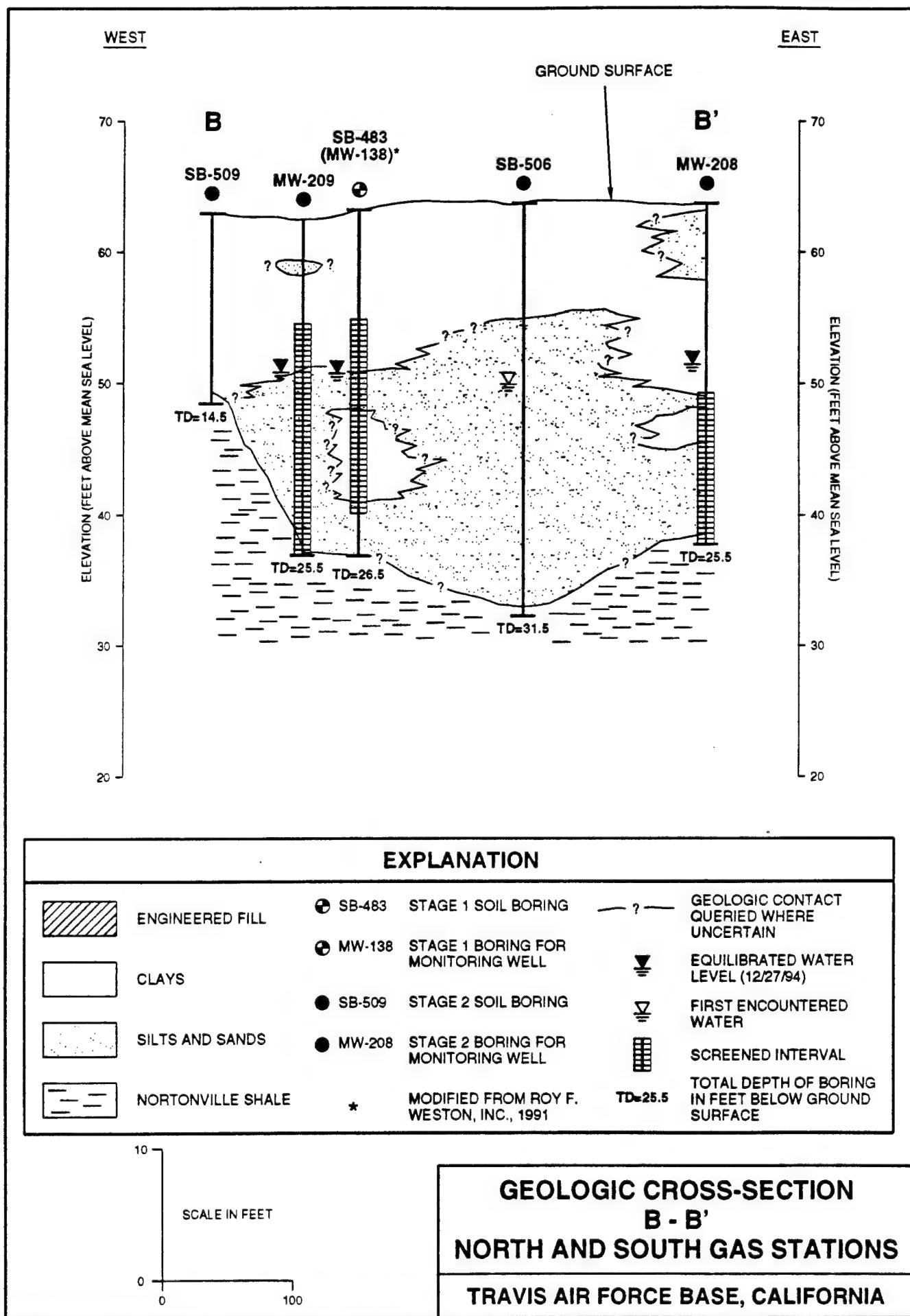


FIGURE 2.7



constrained to flow southward due to an alignment of shallow bedrock along the western side of the SGS and in the northern portion of the NGS.

A groundwater elevation map for December 1994 is presented on Figure 2.8. The map indicates an expected groundwater flow direction toward the south-southeast. Localized semi-confined groundwater conditions were indicated by hydraulic testing and the fact that water levels in many of the wells rose several feet above the water bearing stratum after well installation.

Hydraulic well testing at the NSGS site during the Stage 2 investigation consisted of multiple slug and bail tests and short-term pumping and recovery tests. Analyses by a variety of methods found that 92 percent of the calculated hydraulic conductivities are within the range of 8×10^{-3} centimeters per second (cm/s) (22.7 ft/day) to 4×10^{-4} cm/s (1.1 ft/day). These values are consistent with typical conductivities for silty sands (poor aquifers). Table 2.1 summarizes the hydraulic test results.

2.1.3 Soil Quality

During the Stage 2 RI, soil samples were collected for lithologic description and organic and inorganic analyses. Soil samples collected in June 1994 were analyzed for: total petroleum hydrocarbons as gasoline (TPH-g); total petroleum hydrocarbons as diesel (TPH-d); BTEX; volatile organic compounds (VOCs); semivolatile organic compounds (SVOCs), California LUFT metals, organic lead, ethylene dibromide (EDB), and soil waste disposal parameters. The soil samples collected during installation of monitoring wells in December 1994 were analyzed for TPH-g and BTEX only.

The predominant soil contaminants detected during the Stage 2 RI were BTEX and TPH-g. The maximum detected concentrations were 1,589 milligrams per kilogram (mg/kg) BTEX at SB-504 and 10,100 mg/kg TPH-g at SB-505. SB-505 was located approximately 3 feet south of the SGS UST complex and SB-504 was near the fuel distribution piping. In July and August 1994 the contaminated soil in this area was excavated and the USTs and associated piping were removed and replaced.

Analytical results of organic and inorganic soil samples collected in June 1994 are summarized in Tables 2.2 and 2.3, respectively. Results of soil samples collected in December 1994 are presented in Table 2.4. The locations of soil borings and monitoring wells were shown on Figure 2.5.

The maximum soil contamination detected during the Stage 1 investigation in 1989-1990 was at a depth of 14 feet in SB-480 with a TPH-g concentration of 1,600 mg/kg and in SB-479 at 15 feet with the following BTEX concentrations: 520 mg/kg benzene; 2,600 mg/kg

Table 2.1
HYDRAULIC TESTING RESULTS
June 1994
North and South Gas Stations, Travis AFB, California

WELL	TEST	ANALYSIS METHOD	HYDRAULIC CONDUCTIVITY (meters/sec.)	TRANSMISSIVITY	
				(sq. meters/sec.)	(U.S. gal/day-ft)
MW201	Slug Test, Rising Head #1	Bouwer and Rice ¹ Curve Matching	1.73E-05 9.48E-06	-- --	-- --
	Slug Test, Rising Head #2	Bouwer and Rice Curve Matching	1.87E-05 7.36E-06	-- --	-- --
MW202	Pump Test #1	Curve Matching Jacob's Straight Line Theis (Recovery)	1.93E-05 2.23E-05 4.93E-05	1.06E-04 1.22E-04 2.70E-04	737 851 1,882
	Pump Test #2	Curve Matching Jacob's Straight Line Theis (Recovery)	1.22E-05 4.68E-05 5.83E-05	6.69E-05 2.57E-04 3.20E-04	465 1,786 2,225
MW203	Slug Test, Rising Head	Bouwer and Rice Curve Matching	1.56E-05 5.80E-07	-- --	-- --
MW204	Slug Test, Rising Head	Bouwer and Rice Curve Matching	2.69E-05 3.72E-06	-- --	-- --
MW208	Pump Test	Curve Matching Jacob's Straight Line Theis (Recovery)	9.04E-06 5.31E-06 6.68E-06	1.56E-05 9.16E-06 1.15E-05	108 64 80
MW209	Slug Test, Rising Head #1	Bouwer and Rice Curve Matching	4.98E-05 4.28E-04	-- --	-- --
	Slug Test, Rising Head #2	Bouwer and Rice Curve Matching	6.51E-05 7.63E-05	-- --	-- --
MW210	Slug Test, Rising Head #1	Bouwer and Rice Curve Matching	6.07E-06 7.33E-06	-- --	-- --
	Slug Test, Rising Head #2	Bouwer and Rice Curve Matching	5.80E-06 5.76E-06	-- --	-- --

-- : test not suitable for calculating transmissivity
¹ Bouwer and Rice, 1976; Bouwer, 1989

results.xls

Table 2.2
Soil Contaminant Concentrations of Organic and Fuel Fraction Analytes
North and South Gas Stations, Travis AFB, California - June 1994

Analysis:	Depth (ft bgs)	Aromatic Volatile Hydrocarbons			TPH as Gasoline	TPH as Diesel	Oil & Grease	Volatile Organics			Semivols		
		SW8020	SW8020	SW8015(m)				SW9070(m)	SW8240	SW8240			
Method:	Analyte:	Benzene	Toluene	Ethylbenzene	Xylenes	1,4-DCB		Benzene	Toluene	Ethylbenzene	Xylenes	Acetone	SWB270
								all concentrations in mg/kg					
MW201-A1-0	13.0	0.0016JP		0.0070		5.6		NA	NA	NA	NA	NA	NA
MW201-A2-0	14.5		15		22		1,940	120	NA	NA	NA	NA	NA
MW201-A3-0	18.0	1.6J		18P	23P	1.1JP	2,120	200	NA	NA	NA	NA	NA
MW202-A2-0	13.5	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
MW203-A2-0	14.0												
MW203-A2-1(d)	14.5												
MW204-A2-0	15.0												
MW205-A2-0	15.0												
MW206-A2-0	13.0	9.2JP	32	22	110		1,890	65	NA	NA	NA	NA	NA
MW206-A3-0	16.5	1.8P	0.088	0.17P	0.23P		3.4	NA	NA	NA	NA	NA	NA
MW207-A2-0	14.5	6.0	46P	13P	96P		1,040	65	NA	NA	NA	NA	NA
MW208-A2-0	19.0						NA	NA	NA	NA	NA	NA	NA
MW209-A2-0	12.5						0.17J		NA	NA	NA	NA	NA
MW209-A2-1(d)	13.0								NA	NA	NA	NA	NA
MW210-A2-0	10.5	1.5JP	3.5	16P	44		1,080	340	NA	NA	NA	NA	NA
MW210-A3-0	11.5	0.77	1.1P	1.5	4.1		130		NA	NA	NA	NA	NA
SB501-A2-0	11.5						0.40		NA	NA	NA	NA	NA
SB501-A2-1(d)	13.0								NA	NA	NA	NA	NA
SB502-A2-0	13.0	NA	NA	NA	NA	NA	0.46	NA	NA	NA	NA	NA	NA
SB502-A3-0	16.5	NA	NA	NA	NA	NA	120		NA	NA	NA	NA	NA
SB502-A3-1(d)	15.5	NA	NA	NA	NA	NA	120		NA	NA	NA	NA	NA
SB504-A1-0	11.5	0.059P	0.049P	0.031P	0.12P		12		NA	NA	NA	NA	NA
SB504-A2-0	14.5	99	500P	160	830		8,260	10J	NA	NA	NA	NA	NA
SB504-A3-0	21.5	0.028	0.097	0.018	0.093		2.2		NA	NA	NA	NA	NA
SB505-A1-0	14.5	NA	NA	NA	NA	NA	10,100		NA	NA	NA	NA	NA
SB505-A2-0	16.0	NA	NA	NA	NA	NA	280	32	NA	NA	NA	NA	NA
SB505-A3-0	21.5	NA	NA	NA	NA	NA	2.9		NA	NA	NA	NA	NA
SB506-A1-0	7.5	NA	NA	NA	NA	NA			62.4				0.037
SB506-A1-1(d)	8.0	NA	NA	NA	NA	NA							
SB506-A2-0	14.5	NA	NA	NA	NA	NA	2.2						
SB506-A2-1(d)	13.0	NA	NA	NA	NA	NA							
SB507-A2-0	13.5	15J	64P	46	200		3,040	8J	NA	NA	NA	NA	NA
SB508-A2-0	16.0												
SB509-A2-0	13.0												
SB510-A2-0	11.5	2.9P	6.4	8.1	18P		380	30	NA	NA	NA	NA	NA
SB511-A2-0	11.5	0.013J	0.057	0.045	0.16P		1.6		NA	NA	NA	NA	NA
SB511-A3-0	15.5												

Notes:

bgs : below ground surface

NA : not detected (detection limits will vary depending on dilution factor used)

JP : primary and secondary results are 10 times the method detection limit, but the secondary result does not lie within 25% difference of the primary result.

P : Analyte detected below practical quantitation limit; therefore, result given is an estimated concentration.

(d) : duplicate

NA : not analyzed

DCB = Dichlorobenzene

7/13/95

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Table 2.3
Soil Concentrations of Fuel Additives and Inorganic Parameters
North and South Gas Stations, Travis AFB, California
June 1994

Analysis:		Moisture %	pH	Total Organic Carbon	Lead	Organic Lead	Ethylene Dibromide
Method:		D2216	SW9045	E415.1	SW7421	DHS/LUFT	SW8021
Boring-Sample	Depth (ft bgs)	all concentrations in mg/kg					
MW201-A1-0	13.0	16.1	NA	NA	NA	NA	NA
MW201-A2-0	14.5	24.1	NA	NA	8.49	NA	NA
MW201-A3-0	18.0	20.7	NA	NA	NA	NA	NA
MW202-A2-0	13.5	17.2	5.8	1,800	9.44	NA	NA
MW203-A2-0	14.0	18.4	7.5	710	NA	NA	NA
MW203-A2-1(d)	14.5	19.2	NA	NA	NA	NA	NA
MW204-A2-0	15.0	19.0	NA	NA	NA	NA	NA
MW205-A2-0	15.0	13.5	NA	NA	11.1	NA	NA
MW206-A2-0	13.0	20.4	NA	NA	14.0	NA	NA
MW206-A3-0	16.5	20.2	NA	NA	NA	NA	NA
MW207-A2-0	14.5	21.2	NA	NA	10.9	NA	NA
MW208-A2-0	19.0	17.8	7.4	NA	8.8	NA	NA
MW209-A2-0	12.5	20.6	7.5	520	10.4	NA	NA
MW209-A2-1(d)	13.0	21.3	NA	NA	11.0	NA	NA
MW210-A2-0	10.5	20.1	NA	NA	10.8	NA	NA
MW210-A3-0	11.5	22.7	NA	NA	NA	NA	NA
SB501-A2-0	11.5	16.7	NA	NA	15.3	NA	NA
SB501-A2-1(d)	13.0	21.6	NA	NA	NA	NA	NA
SB502-A2-0	13.0	14.3	NA	NA	NA	NA	NA
SB502-A3-0	16.5	22.1	NA	NA	15.7	NA	NA
SB502-A3-1(d)	15.5	15.0	NA	NA	12.6	NA	NA
SB504-A1-0	11.5	14.0	NA	NA	NA	NA	NA
SB504-A2-0	14.5	19.5	8.0	1,400	12.1	0.37J	NA
SB504-A3-0	21.5	19.4	NA	NA	NA	NA	NA
SB505-A1-0	14.5	14.9	NA	NA	NA	NA	NA
SB505-A2-0	16.0	19.2	NA	NA	13.1	NA	NA
SB505-A3-0	21.5	23.3	NA	NA	NA	NA	NA
SB506-A1-0	7.5	16.3	NA	NA	11.3	0.81	NA
SB506-A1-1(d)	8.0	23.2	NA	NA	12.2	NA	NA
SB506-A2-0	14.5	16.1	NA	NA	NA	NA	NA
SB506-A2-1(d)	13.0	15.8	NA	NA	NA	NA	NA
SB507-A2-0	13.5	18.1	NA	NA	NA	NA	NA
SB508-A2-0	16.0	15.6	8.0	560	7.4	NA	NA
SB509-A2-0	13.0	18.9	8.8	920	19.8	NA	NA
SB510-A2-0	11.5	20.1	8.0	1,100	19.5	NA	NA
SB511-A2-0	11.5	21.0	NA	NA	14.4	NA	NA
SB511-A3-0	15.5	21.2	NA	NA	NA	NA	NA

Notes:

bgs : below ground surface

NA : not detected (detection limits will depend on dilution factor used)

NA : not analyzed

(d) : duplicate

J : Analyte detected below practical quantitation limit;
therefore, result given is an estimated concentration.

Table 2.4
Soil Contaminant Concentrations (Second Round)
North and South Gas Stations, Travis AFB, California
December 1994

Analysis:		Aromatic Volatile Hydrocarbons							TPH as Gasoline
Method:		SW8020							SW8015(m)
Analyte:		Benzene	Toluene	Ethylbenzene	Xylenes	Chlorobenzene	1,2-DCB	1,4-DCB	TPH-g
Boring-Sample	Depth (ft bgs)	all concentrations in $\mu\text{g}/\text{kg}$							
MW211-A1-0	11.5	2.02	6.32	21.5	59.8	0.632 J	13.3	1.52	2,390
MW211-A1-0 ¹	11.5	19.8	24.8	94.2	263		48.1	3.13 J	NA
MW212-A1-0	16.5								
MW213-A1-0	10.5								
MW214-A1-0	10.5								
MW214-A1-1(d)	10.0								

Notes:

bgs : below ground surface

¹ : two different columns taken from same soil sample yielded strongly varied results;
 sample is assumed to be non-homogeneous.

(d) : duplicate

Analyte Abbreviations

1,x-DCB = Dichlorobenzenes

NA : not analyzed

: not detected (detection limits will vary depending on dilution factor used)

J : Analyte detected below practical quantitation limit; therefore, result given is an estimated concentration.

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7/13/95

toluene; 610 mg/kg ethylbenzene, and 2,900 mg/kg total xylenes. Borings SB-479 and SB-480 were both located within 25 feet of the SGS UST complex. Boring SB-479 was converted to MW-141, where the highest TPH-g concentration was detected in groundwater during the Stage 1 RI [9,800 milligrams per liter (mg/L) TPH-g]. Appendix B contains a summary of soil and groundwater analytical data from the Stage 1 investigation.

2.1.4 Groundwater Quality and Chemistry

As part of the Stage 2 RI, groundwater samples were collected from 17 monitoring wells in July 1994 and analyzed for TPH-g, TPH-d, BTEX, VOCs and SVOCs, California LUFT metals, organic lead, EDB and wastewater disposal parameters. Analytical results of the July 1994 sampling event showed that the predominant groundwater contaminants are gasoline and BTEX. Groundwater samples collected from 12 monitoring wells during December 1994 were analyzed for TPH-g, BTEX, VOCs, sulfate, nitrate-nitrogen, and total dissolved solids (TDS).

The highest level of contamination was detected in MW-138 with the following concentrations: 103,060 µg/L BTEX, 1,500 mg/L TPH-d, and 142 mg/L TPH-g. Free product was measured in MW-138 with a thickness of 4 inches. MW-138 is located approximately 75 feet south of the SGS UST source. At most other monitoring wells, TPH-g concentrations were higher than TPH-d concentrations. Analytical results of groundwater sampling are summarized in Tables 2.5 and 2.6. Isopleth maps of TPH-g and benzene concentrations based on these results are shown on Figures 2.9 and 2.10, respectively.

Appendix B contains a summary of groundwater analytical data from the Stage 1 investigation.

2.2 DEVELOPMENT OF CONCEPTUAL MODEL

A conceptual model is a three-dimensional representation of the hydrogeologic system based on available geological, hydrological, climatological, and geochemical data. The purpose of developing a site conceptual model is to provide an understanding of the mechanism for contaminant fate and transport and to identify additional data requirements. The model describes known and suspected sources of contamination, types of contamination, affected media, and contaminant migration pathways. The model provides a foundation for formulating decisions regarding additional data collection activities and potential remedial actions. The conceptual model for the NSGS site will be used to aid in selecting additional data collection points and to identify appropriate data needs for modeling hydrocarbon degradation using the Bioplume II model.

Table 2.5

Groundwater Contaminant Concentrations of Organic and Fuel Fraction Analytes
North and South Gas Stations, Travis AFB, California

July 1994

Analysis:	Aromatic Volatile Hydrocarbons	TPH as Gasoline				Oil & Grease				Volatile Organics				Semi-vol
		SW8020	SW8015	SW8015	E413.1	SW8240	SW8240	SW8240	SW8240	Acetone	Xylenes	Ethylbenzene	Toluene	
Analyte:	Benzene	Toluene	Ethylbenzene	Xylenes	TPH-g	TPH-d	O&G	Benzene	Ethylbenzene	Xylenes	Acetone	1,2-DCA	Chloroform	Naphthalene
Well-Sample														
MW135-01	NA	NA	NA	NA	94,900	19,900	NA	340	190J	1,970	6,650		96J	NA
MW136-01	NA	NA	NA	NA	630	420J	430	37		14				
MW136-01-1(d)	NA	NA	NA	NA	NA	NA	430	NA	NA	NA	NA	NA	NA	4J
MW137-01	380P	40P	93	100	3,470	900	NA	NA	NA	NA	NA	NA	NA	NA
MW138-01	NA	NA	NA	NA	142,000	1,500,000	NA	21,500	38,500	7,160	35,900			NA
MW139-01	NA	NA	NA	NA	9,440	1,120	NA	840	520	600	1,170			NA
MW139-01-1(d)	NA	NA	NA	NA	8,590	370J	NA	NA	NA	NA	NA	NA	NA	NA
MW140-01	1.7	2.0P			580	820	NA	NA	NA	NA	NA	NA	NA	NA
MW141-01	NA	NA	NA	NA	31,000	2,200	NA	7,380	11,600	1,640	7,210			NA
MW201-01			13	1,180	96J	NA	NA	NA	NA	NA	NA	NA	NA	NA
MW201-01-1(d)			10P	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
MW202-01							NA	NA	NA	NA	NA	NA	NA	NA
MW203-01							NA	NA	NA	NA	NA	NA	NA	NA
MW204-01	1.6P	8.0	6.0	34	320	NA	NA	NA	NA	NA	NA	NA	NA	NA
MW205-01						NA	NA	NA	NA	NA	NA	NA	NA	NA
MW206-01	3,900	430	280	440	11,800	1,820	NA	NA	NA	NA	NA	NA	NA	NA
MW207-01	NA	NA	NA	NA	25,800	3,330	NA	720	4,400	700	5,060	76		NA
MW207-01-1(d)	NA	NA	NA	NA	29,800	3,480	NA	710	4,320	710	5,290	71		NA
MW208-01	NA	NA	NA	NA	350	280J	NA	NA	NA	NA	NA	NA	NA	NA
MW209-01	NA	NA	NA	NA	3,080	19,900	3,770	NA	NA	NA	NA	8		NA
MW210-01	1,270	1,510	720											NA

Notes:

NA : not detected (detection limits will vary depending on dilution factor used); for the SW8240 series, only the analytes that were detected are shown on this table;

NA : not analyzed
 (d) : duplicate
 P : Both primary and secondary results are 10 times the method detection limit, but the secondary result does not lie within 25% difference of the primary result.

J : Analyte detected below practical quantitation limit; therefore, result given is an estimated concentration.

a : California Maximum Contaminant Levels as set by California Code of Regulations, Title 26, sections 22-64435 to 22-64473.

b : Federal Maximum Contaminant Levels as set by "Drinking Water Regulations and Health Advisories", May 1994 EPA 822-R-94-001

c : Proposed California MCLs as of June 21, 1994

Table 2.6
Groundwater Contaminant Concentrations (Second Round)
North and South Gas Stations, Travis AFB, California
December 1994-January 1995

Analysis:	Aromatic Volatile Hydrocarbons				TPH as Gasoline				Volatile Organics				Inorganic Parameters				
	SW820				SW8015				SW8240				300.0		300.0		
Method:	Benzene	Toluene	Ethylbenzene	Xylenes	1,4-DCB	TPH-g	DCM	Acetone	Toluene	Styrene	Nitrate	Nitrite	Sulfate	TDS			
Well-Sample	concentrations in $\mu\text{g/L}$																
MW136-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	180	NA	
MW141-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	275	NA	
MW202-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	4,770	NA	
MW206-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	13.6	NA	
MW208-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	206	NA	
MW210-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	754	NA	
MW211-01	67.8	60.4	71.4	247	17	2,190	NA	NA	NA	NA	NA	NA	NA	NA	3	2,330	5,800
MW212-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	3.3	1,830	4,830
MW212-01-1(d)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	4,780
MW213-01																	3,060
MW213-01-1(d)																	3,080
MW214-01																	3,040

HP-6 ^g	NA															
CPT-7 ^g	NA															
CPT-30 ^g	NA															

Notes:

NA : not detected (detection limits will vary depending on dilution factor used); for the SW8240 series, only the analytes that were detected are shown on this table; trichloroethene was not detected.

NA : not analyzed

(d) : duplicate

J : Analyte detected below practical quantitation limit; therefore, result given is an estimated concentration.

a : California Maximum Contaminant Levels as set by California Code of Regulations, Title 26, sections 22-64435 to 22-64473.

b : Federal Maximum Contaminant Levels as set by "Drinking Water Regulations and Health Advisories", May 1994 EPA 822-R-94-001.

c : Federal Secondary Levels as set by "Drinking Water Regulations and Health Advisories", May 1994 EPA 822-R-94-001.

e : Proposed California MCLs as of June 21, 1994

f : Cone Penetrometer Test™ confirmation samples collected with a Hydropunch™ sampler.

Cal. MCL ^a	1	150 ^c	700 ^e	1,750	5	--	5	--	150	100	45	1	250 ^f	500 ^f
MCL ^b	5	1,000	700	10,000	75	--	5	--	1,000	100	10	1	250 ^c	500 ^c

Successful conceptual model development involves:

- Defining the problem to be solved;
- Integrating available data, including:
 - Local geologic and topographic data,
 - Hydraulic data,
 - Site stratigraphic data,
 - Contaminant concentration and distribution data;
- Evaluating contaminant fate and transport characteristics;
- Identifying contaminant migration pathways;
- Identifying potential receptors; and
- Determining additional data requirements.

2.2.1 Intrinsic Remediation and the Bioplume II Model

After a site has been adequately characterized, fate and transport analyses can be performed to determine the potential for contaminant migration and whether any exposure pathway for human or ecological receptors is complete. The Bioplume II model has proved useful for predicting BTEX plume migration and contaminant attenuation by natural biodegradation. The Bioplume II model (Rifai *et al.*, 1988) can be used to evaluate critical groundwater fate and transport processes that may be involved in some of the migration pathways to human and ecological receptors. Quantitative fate and transport analyses can be used to determine what level and extent of remediation is required.

An important consideration in determining whether fuel hydrocarbon contamination presents a substantial threat to human health and the environment and what type of remedial alternative will be most cost effective in eliminating or abating these threats is an accurate estimate of the potential for natural biodegradation of BTEX compounds in the groundwater. Over the past two decades, numerous laboratory and field studies have demonstrated that subsurface microorganisms can degrade a variety of hydrocarbons (Lee 1988). This process occurs naturally when sufficient oxygen (or other electron acceptors) and nutrients are available in the groundwater. The rate of natural biodegradation is generally limited by the lack of electron acceptors rather than by the lack of nutrients such as nitrogen or phosphorus.

2.2.2 Biodegradation of Dissolved BTEX Contamination

The Bioplume II model is a well-documented and widely accepted numerical model available for modeling the fate and transport of fuel hydrocarbons under the influence of advection, dispersion, sorption, and natural aerobic and anaerobic biodegradation. The positive effect of these processes on reducing the actual mass of fuel-related contamination dissolved in groundwater has been termed intrinsic remediation. The advantages of intrinsic remediation include: (1) contaminants are transformed to innocuous byproducts (e.g., carbon dioxide and water), not just transferred to another phase or location within the environment; (2) current pump-and-treat technologies are energy-intensive and generally not as effective in reducing residual contamination; (3) the process is nonintrusive and allows continuing use of infrastructure during remediation; (4) current engineered remedial technologies may pose a greater risk to potential receptors than intrinsic remediation because contaminants may be transferred into the atmosphere during remediation activities; and (5) intrinsic remediation is far less costly than conventional, engineered remedial technologies.

To estimate the impact of natural attenuation on the fate and transport of BTEX compounds dissolved in groundwater at a site, two important lines of evidence must be demonstrated (Wiedemeier *et al.*, 1995). The first is a documented loss of contaminants at the field scale. Dissolved concentrations of biologically-recalcitrant tracers found in most fuel contamination are used in conjunction with aquifer hydrogeologic parameters, such as groundwater seepage velocity and dilution, to demonstrate that a reduction in the total contaminant mass is occurring at the site. The second line of evidence involves the use of chemical analytical data in mass balance calculations to show that areas with BTEX contamination can be correlated to areas with depleted electron acceptor (e.g., oxygen, nitrate, and sulfate) concentrations and increases in metabolic fuel degradation byproduct concentrations (e.g., methane and ferrous iron). With this site-specific information, the Bioplume II computer model can be used to simulate the fate and transport of dissolved BTEX compounds under the influence of the process of natural attenuation.

The Bioplume II model is based upon the US Geological Survey (USGS) two-dimensional (2-D) solute transport model (Konikow and Bredehoeft, 1978), which has been modified to include a biodegradation component that is activated by a superimposed plume of dissolved oxygen. Bioplume II solves the USGS 2-D solute equation twice, once for hydrocarbon concentrations in the groundwater and once for a dissolved oxygen plume. The two plumes are then combined using superposition at every particle move to simulate biological reactions between fuel products and oxygen. If site conditions indicate that electron acceptors other

than dissolved oxygen are being utilized, biodegradation of contaminants by anaerobic processes is simulated using a first-order anaerobic decay rate.

2.2.3 Initial Conceptual Model

Site geologic data were previously integrated to produce geologic cross-sections of the site. Cross-sections A-A' and B-B' (see Figures 2.6 and 2.7) show the dominant hydrostratigraphic units present at the site. The groundwater elevation contour prepared using groundwater elevation data taken in December 1994 was shown on Figure 2.8.

Alluvial sands encountered during site investigations were predominantly fine grained with variable amounts of silt and clay. The overlying clay also acts locally as an aquitard. The clay content often decreased with increasing depth and the sand in several borings became coarser with depth. The sand that makes up the shallow aquifer at the site was saturated below a depth of approximately 14 to 16 feet bgs.

The depth to groundwater at the NSGS site appears to vary seasonally. Depths to groundwater for all monitoring wells were between 9.0 and 14.2 feet bgs in July 1994, and between 7.9 and 14.1 feet bgs in December 1994. The gradient calculated from water levels was approximately 0.002 foot per foot (ft/ft) toward the south-southeast. Groundwater appears to be constrained to flow southward due to an alignment of shallow bedrock along the western side of the SGS and in the northern portion of the NGS.

Considering the underlying bedrock (Nortonville Shale) which acts as a thick confining layer and the resulting absence of vertical gradients, groundwater migration to deeper aquifers should be minimal. Based on available data, Parsons ES will model the site as a semi-confined, fine-grained sand aquifer. This conceptual model will be modified as necessary as additional site hydrogeologic data become available.

LNAPL (light, non-aqueous phase liquid) is present at the NSGS site as evidenced by measurement of free product in MW-135 and MW-138 at 1 inch and 4 inches in thickness, respectively. However, LNAPL appears to be limited to the areas immediately downgradient of the NGS and SGS tank pits. The fuel/water partitioning models of Bruce *et al.* (1991) or Cline *et al.* (1991) will be used to provide a conservative source term to model the partitioning of BTEX compounds from the free product phase into the groundwater. In order to use one of these models, samples of free product will be collected and analyzed for mass fraction of BTEX compounds. In wells containing LNAPL, Parsons ES will attempt to collect groundwater samples immediately below LNAPL, where possible.

During UST and associated piping removal operations at the SGS in 1994, most of the contaminated soil in the area was removed. However, some visibly contaminated soil was

observed underneath the western edge of the station building (Building 170) and was not excavated. The soil contamination detected in borings downgradient of both the NGS and SGS tank pits is likely the result of free product migration and adsorption from contaminated groundwater. Therefore, except for the LNAPL present near the former tank pits and the unknown amount of contaminated soil beneath Building 170, the major sources of dissolved groundwater contamination have probably been removed at the site.

The chemicals of concern for groundwater at or migrating from the NSGS site are BTEX, TPH-g, and TPH-d. BTEX compounds will be the primary focus of this intrinsic remediation study because of their regulatory importance; however, where appropriate to provide further site characterization information, TPH-g and TPH-d concentrations in groundwater will also be measured. The Bioplume II model will simulate the degradation of BTEX at the UST site and will be used to predict the concentration and extent of the contaminant plume in the groundwater over time.

The chemicals of concern for the site are expected to partition from contaminated unsaturated soil, which contains fuel residuals, or from mobile LNAPL floating on the groundwater surface into the underlying groundwater, and migrate downgradient as a dissolved contaminant plume. In addition to the effects of mass transport mechanisms (volatilization, dispersion, diffusion, and adsorption), these dissolved contaminants will likely be removed from the groundwater system by naturally occurring destructive attenuation mechanisms, such as biodegradation. The effects of these fate and transport processes on the dissolved groundwater plume will be investigated using the quantitative groundwater analytical data and the solute-transport model, Bioplume II. Data collection and analysis requirements are discussed in Section 3 of this work plan.

2.2.4 Potential Pathways and Receptors

Potential pathways for contaminant migration from the NSGS site include surface, subsurface, and air routes. The Stages 1 and 2 RIs indicated that the primary potential migration paths for contaminants at the site is from the remaining contaminated soils and free product at the site to the groundwater and from the groundwater to potential receptors via consumption or other use.

The nondegradation policy adopted by the California State Water Resources Control Board under Resolution 68-16 limits discharges that can potentially degrade existing groundwater (i.e., discharges of water with contaminant concentrations that are significantly greater than background levels). The resolution requires that the best practicable treatment or control of the discharge be used to assure that "(a) a pollution or nuisance will not occur and

(b) the highest water quality consistent with maximum benefit to the people of the State will be maintained." Under the nondegradation policy, the Regional Water Quality Control Board considers groundwater a potential receptor for contaminants migrating through the vadose zone, or contaminants transported through soils via infiltration of surface water.

According to the nondegradation policy, any contaminant constituent detected in groundwater at a concentration above background levels potentially degrades water quality. Potential release of contaminant constituents into the groundwater may be modeled for the location where contaminants potentially affect the groundwater. Modeling predicts the concentration entering the groundwater at a specific point and time.

There are no known operating potable or nonpotable water wells located downgradient within 2 miles of the site. The potential for contaminant migration by surface or air pathways is negligible except during remedial or construction activities.

The potential for exposure to contaminated water originating from the site through drinking water supplies is low because of the restricted nature of the Base and lack of potable water wells on Base property. The closest downgradient wells which are used for domestic, stock watering, industrial, and irrigation purposes are 2 miles south of the site. Potable water for the Base and for surrounding areas is supplied through a municipal drinking water treatment plant.

Potential preferential contaminant migration pathways such as groundwater discharge points and subsurface utility corridors (artificial conduits) will be identified during the field work phase of this project. The Stage 2 investigation revealed no points of groundwater discharge to surface water in the site vicinity. Because the site is on a secured military Base, Base workers and possibly ecological receptors are the probable current receptors of any soil, surface water, or sediment contamination. Since the gas station area is completely paved and the zone of contamination is capped with approximately 10 feet of clay, potential for exposure appears to be negligible whether by volatilization from the groundwater or to ecological receptors.

SECTION 3

COLLECTION OF ADDITIONAL DATA

To complete the TS and to evaluate the rates and patterns of intrinsic remediation of fuel-related contaminants, additional site-specific hydrogeologic data will be collected. The physical and chemical hydrogeologic parameters listed below will be determined during the field work phase of the TS.

Physical hydrogeologic characteristics to be determined include:

- Depth from measurement datum to the groundwater surface in existing monitoring wells and water-level-accessible monitoring points;
- Estimate of dispersivity, where possible;
- Stratigraphic analysis of subsurface media;
- Groundwater temperature; and
- Determination of extent and thickness of mobile and residual LNAPL.

Chemical hydrogeologic characteristics to be determined include:

- Dissolved oxygen (DO) concentration;
- Specific conductance;
- pH;
- Chemical analysis of free product (if present) to determine mass fraction of BTEX; and
- Additional chemical analysis of groundwater for the parameters listed in Table 3.1.

To obtain these data, groundwater and free product samples will be collected and analyzed. The following sections describe the procedures that will be followed when collecting additional site-specific data.

Drilling and monitoring point installation will be accomplished using the Geoprobe® system, which is described in Section 3.1. Procedures to be used to collect soil core samples for stratigraphic analysis are described in Section 3.1. Procedures to be used to sample existing groundwater monitoring wells and newly installed groundwater monitoring points are described in Section 3.2.

TABLE 3.1
ANALYTICAL PROTOCOL FOR
GROUNDWATER SAMPLES
NORTH AND SOUTH GAS STATIONS
INTRINSIC REMEDIATION TS
TRAVIS AFB, CALIFORNIA

MATRIX	METHOD	FIELD (F) OR ANALYTICAL LABORATORY (L)
WATER		
Total Iron	Colorimetric, HACH Method 8008 (or similar)	F
Ferrous Iron (Fe+2)	Colorimetric, HACH Method 8146 (or similar)	F
Ferric Iron (Fe+3)	Difference between total and ferrous iron	F
Manganese	Colorimetric, HACH Method 8034 (or similar)	F
Sulfide	Colorimetric, HACH Method 8131 (or similar)	F
Sulfate	Colorimetric, HACH Method 8051 (or similar)	F
Redox Potential	A2580B, direct reading meter	F
Oxygen	Direct reading meter	F
pH	E150.1/SW9040, direct reading meter	F
Conductivity	E120.1/SW9050, direct reading meter	F
Temperature	E170.1	F
Alkalinity (Carbonate [CO ₃ -2] and Bicarbonate [HCO ₃ -1])	Titrimetric, HACH Method 8221 (or similar)	F
Carbon Dioxide	CHEMetrics Method 4500	F
Nitrate	E300 or SW9056	L
Nitrite	E300 or SW9056	L
Chloride	E300 or SW9056	L
Sulfate	E300 or SW9056	L
Alkalinity	E150.1	L
Methane	RSKSOP-147	L
Total Organic Carbon	A5310C (RSKSOP-102)	L
Aromatic Hydrocarbons (Including Trimethylbenzene, Tetramethylbenzene, and Chlorobenzene)	SW8020 (RSKSOP-133)	L
Total Petroleum Hydrocarbons	SW8015M	L
Free Product	SW8020, Density	L
Ammonia--Diss. Gas in Water	Standard Method 4500-NH3F	L

No additional soil samples for laboratory analysis will be collected during this investigation. The extent of soil contamination and all necessary soil parameters for input into the Bioplume II model (e.g. total organic carbon) were collected during the Stage 1 and Stage 2 investigations. However, soil core samples will be collected for stratigraphic analysis at locations where new monitoring points are installed.

No additional aquifer testing (e.g. pumping tests, slug tests) will be performed during this investigation. The previously calculated hydraulic conductivities from the Stage 2 RI (see Section 2.1) will be used to estimate the velocity of groundwater and contaminants in the shallow saturated zone and used as inputs to the Bioplume II model. The range of hydraulic conductivity values previously calculated will be used to guide the sensitivity analysis.

3.1 MONITORING POINT INSTALLATION

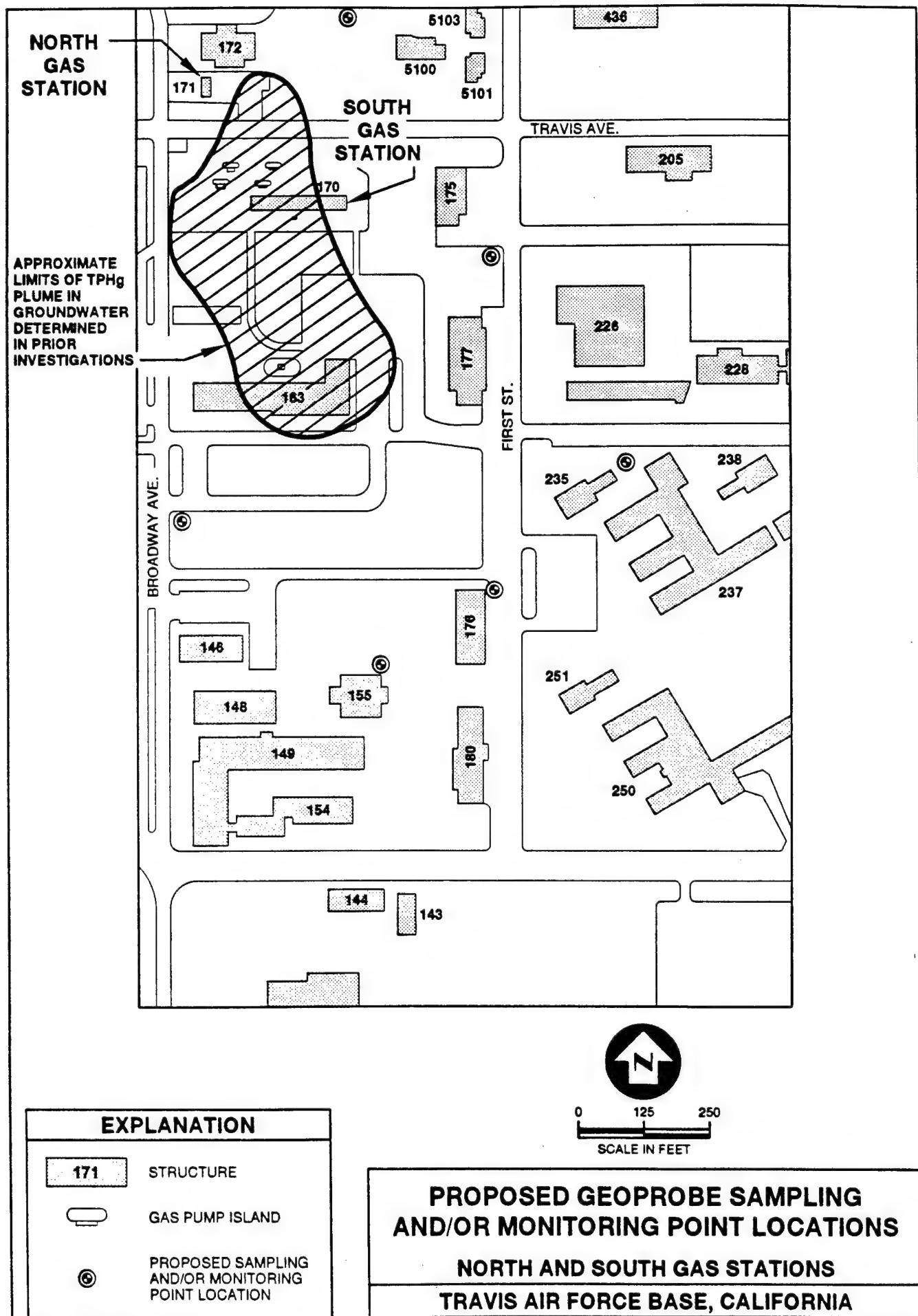
To further characterize the hydrogeologic and geochemical conditions of the shallow subsurface, up to 6 groundwater monitoring points may be installed at the site to supplement the existing 21 monitoring wells. The monitoring points will be installed using Geoprobe Direct Push Technology. If existing background monitoring wells can be identified on Base which are appropriate for the NSGS site, they may be sampled in lieu of installing up to 2 of the new monitoring points. Groundwater grab samples may also be collected at additional locations using the Geoprobe® apparatus. The following sections describe the proposed sampling locations and intervals, monitoring point installation, grab sampling, monitoring point development, and equipment decontamination procedures.

Details on groundwater sampling at the existing 21 monitoring wells at the site are discussed in Section 3.2. Further sampling of the existing monitoring wells is needed to supplement geochemical data collected during the limited intrinsic remediation investigation performed under the Stage 2 RI (see Appendix D) and to evaluate any changes in the contaminant plume extent or geometry.

3.1.1 Monitoring Point Locations and Completion Intervals

The locations of the 6 proposed additional groundwater monitoring points are identified on Figure 3.1. The exact locations for these new monitoring points will be determined based on previous site data and site data generated by Parsons ES during the proposed field activities. New monitoring point locations will be selected to provide hydrogeologic and geochemical data necessary for successful implementation of the Bioplume II model and to monitor potential fuel hydrocarbon migration from the site.

FIGURE 3.1



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The new monitoring point locations will be selected to define three aspects of the site: 1) the geochemistry along the periphery of the previously defined contaminant plume, 2) the background concentration of electron acceptors and electron donors in native groundwater, and 3) the future changes in contaminant concentration and geochemistry downgradient of the contaminant plume. Where appropriate, existing Base background monitoring wells will be used in lieu of up to 2 new monitoring points.

Each monitoring point will have a screened interval of 1 meter. One nested monitoring pair will have a point with a shallow screened interval and a point with a deep screened interval. As an alternative to the nested monitoring point, a single monitoring point with a deep screened interval may be installed adjacent to an existing monitoring well with a shallow screened interval.

The exact depth of monitoring points will be determined by the Parsons ES field scientist depending on site conditions. The proposed screened intervals of 1 meter for shallow and deep monitoring points will help mitigate the dilution of water samples from potential vertical mixing of contaminated and uncontaminated groundwater in the monitoring point casing, and will give important information on the nature of vertical hydraulic gradients in the area. Adjustments of the depth and length of the screened interval of the monitoring points may be necessary in response to actual aquifer conditions and contaminant distribution identified during Geoprobe® testing.

3.1.2 Monitoring Point Installation Procedures

3.1.2.1 Pre-Placement Activities

All necessary digging, coring, and drilling permits will be obtained prior to mobilizing to the field. In addition, all utility lines will be located, and proposed drilling locations will be cleared prior to any intrusive activities.

Base personnel will be responsible for identifying the location of all utility lines, USTs, fuel lines, or any other underground infrastructure prior to any sampling activities. All necessary digging permits will be obtained by Base personnel prior to mobilizing to the field. Base personnel will also be responsible for acquiring drilling and monitoring point installation permits for the proposed locations. Parsons ES will be responsible for providing adequate notice to Base personnel for the locations of intrusive activities prior to mobilization and will provide trained operators for the Geoprobe®.

3.1.2.2 Geoprobe Direct Push Technology

The Geoprobe® system is a hydraulically powered percussion/probing machine used to advance sampling tools through unconsolidated soils. This system provides for the rapid collection of soil, soil gas, and groundwater samples at shallow depths while minimizing the generation of investigation-derived waste materials. Figure 3.2 is a diagram of the Geoprobe® system. The following sections describe soil sample collection methods, well point installation methods, and decontamination methods using the Geoprobe® system.

Soil samples will be collected for lithologic description using a probe-drive sampler. The probe-drive sampler serves as both the driving point and the sample collection device and is attached to the leading end of the probe rods. To collect a soil sample, the sampler is pushed or driven to the desired sampling depth, the drive point is retracted, which opens the sampling barrel, and the sampler is subsequently pushed into the undisturbed soils. The soil cores are retained within brass, stainless steel, or clear acetate liners inside the sampling barrel. The probe rods are then retracted, bringing the sampling device to the surface. The soil sample can then be extruded from the liners for logging or, when required, the liners can be capped and undisturbed samples submitted to the analytical laboratory for testing.

If the probe-drive sampling techniques described above are inappropriate, inadequate, or unable to efficiently provide sufficient soil samples for the characterization of the site, continuous soil samples will be obtained from conventional core boreholes using a hand auger or similar method judged acceptable by the Parsons ES field scientist. Procedures will be modified, if necessary, to ensure good sample recovery.

The Parsons ES field scientist will be responsible for observing all field investigation activities, maintaining a detailed descriptive log of all subsurface materials recovered during soil coring, and photographing representative samples. An example of the proposed geologic boring log form is presented on Figure 3.3. The descriptive log will contain:

- Sample interval (top and bottom depth);
- Sample recovery;
- Presence or absence of contamination;
- Lithologic description, including relative density, color, major textural constituents, minor constituents, porosity, relative moisture content, plasticity of fines, cohesiveness, grain size, structure or stratification, relative permeability, and any other significant observations; and
- Depths of lithologic contacts and/or significant textural changes measured and recorded to the nearest 0.1 foot.

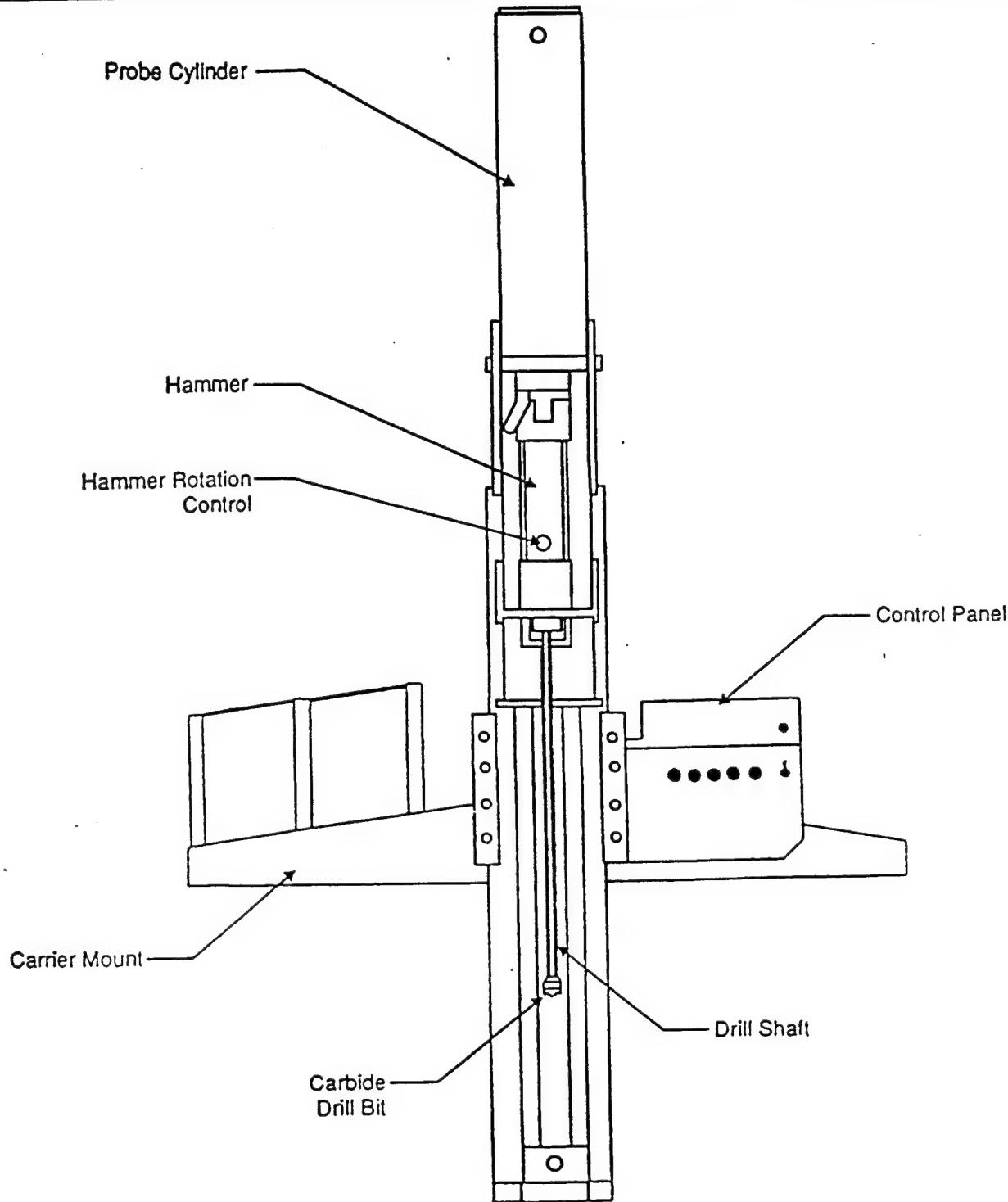


FIGURE 3.2
CROSS-SECTION
OF GEOPROBE

North and South Gas Station
Intrinsic Remediation TS
Travis AFB, California



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Alameda, California

GEOLOGIC BORING LOG

BORING NO.: _____ CONTRACTOR: _____ DATE SPUD: _____
 CLIENT: AFCEE RIG TYPE: _____ DATE CMPL.: _____
 JOB NO.: 722450.27 DRLG METHOD: _____ ELEVATION: _____
 LOCATION: TRAVIS AFB BORING DIA.: _____ TEMP: _____
 GEOLOGIST: _____ DRLG FLUID: _____ WEATHER: _____
 COMMENTS: _____

Elev (ft)	Depth (ft)	Pro- file	US CS	Geologic Description	Sample	Sample	Penet Res	PID(ppm)	TLV(ppm)	BTEX(ppm)	TOTAL (ppm)	TPH (ppm)
					No.	Depth (ft)						
	- 1 -											
	- 5 -											
	- 10 -											
	- 15 -											
	- 20 -											
	- 25 -											
	- 30 -											
	- 35 -											

NOTES

bgs - Below Ground Surface
 GS - Ground Surface
 TOC - Top of Casing
 NS - Not Sampled
 SAA - Same As Above

SAMPLE TYPE

D - DRIVE
 C - CORE
 G - GRAB

 Water level drilled

FIGURE 3.3

GEOLOGIC BORING LOG

North and South Gas Station
 Intrinsic Remediation TS
 Travis AFB, California



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Alameda, California

3.1.2.3 Equipment and Monitoring Point Materials Decontamination

Monitoring point installation and completion materials will be inspected by the field scientist and determined to be clean and acceptable prior to use. If not factory sealed, the well points and tubing will be cleaned prior to use with a high-pressure, steam/hot-water cleaner using approved water. Materials that cannot be cleaned to the satisfaction of the field scientist will not be used.

Prior to arriving at the site, and between each sampling location, probe rods, tips, sleeves, pushrods, samplers, tools, and other downhole equipment will be decontaminated using a high-pressure, steam/hot water wash. Only potable water will be used for decontamination. All rinse water will be collected in containers provided by Parsons ES.

As carried out during the Stage 2 RI, wastewater will be placed in a temporary holding tank in the staging area south of the SGS. The Fairfield-Suisun Sewer District (FSSD) will allow additional wastewater discharges up to a total of approximately 7,000 gallons to be released into the sanitary sewer under the terms of the temporary discharge permit filed by Parsons ES and dated 7 September 1994. Water that contains free product or visible oil sheens will not be added to the holding tank. Instead, visibly contaminated water will be contained in drums.

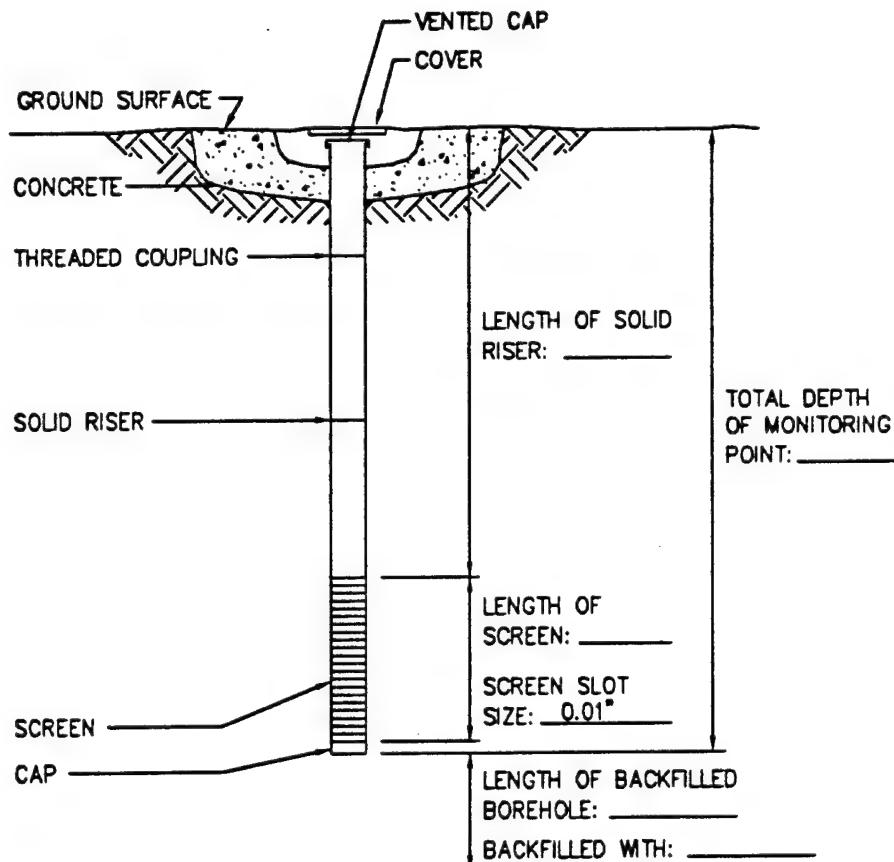
Parsons ES will be responsible for sampling and characterizing the drum contents and will subcontract offbase disposal of the drums, if necessary. Travis AFB will be responsible for providing their EPA generator identification and signing the manifest prior to disposal.

Potable water to be used during equipment cleaning, decontamination, or grouting will be obtained from one of the Base water supplies. Water use approval will be verified by contacting the appropriate facility personnel. The field scientist will make the final determination as to the suitability of site water for these activities. Precautions will be taken to minimize any impact to the surrounding area that might result from decontamination operations.

3.1.2.4 Installation and Materials

This section describes the procedures to be used for installation of monitoring points. Monitoring points will be installed using either 0.375-inch Teflon® tubing connected to a 0.5-inch-diameter stainless steel screen or a 0.5-inch inside-diameter (ID)/0.75-inch outside-diameter (OD) PVC screen and casing. Monitoring point construction details will be noted on a Monitoring Point Installation Record form (Figure 3.4). This information will become part of the permanent field record for the site.

MONITORING POINT INSTALLATION RECORD



(NOT TO SCALE)

STABILIZED WATER LEVEL _____ FEET
B BELOW DATUM.

TOTAL MONITORING POINT DEPTH ____ FEET
BELOW DATUM.

GROUND SURFACE _____ FEET

FIGURE 3.4
**MONITORING POINT
INSTALLATION RECORD**

North and South Gas Station Intrinsic Remediation TS Travis AFB, California



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Alameda, California

3.1.2.4.1 Deep Monitoring Points

The deep monitoring points will be installed in boreholes punched using the Geoprobe®. The deep monitoring points will be constructed of a sacrificial drive point attached to a length of 0.5-inch-diameter stainless steel mesh or slotted schedule 40 polyvinyl chloride (PVC) well screen, which is in turn connected to 0.375-inch Teflon® tubing (steel screen) or 0.5-inch PVC casing (PVC screen).

To install the deep monitoring points, the borehole is punched and sampled to several feet above the target depth for the monitoring point. The probe rods are withdrawn from the borehole, and the soil sampler is replaced with the well point assembly. An appropriate length of Teflon® tubing is threaded through the probe rods and attached to the well point. The assembly is lowered into the borehole and then driven down to the target depth and sampling zone. The probe rods are removed, leaving the sacrificial tip, screen assembly and tubing behind. The saturated soil formation is likely to cave in around the screen assembly; where this does not occur, silica sand will be emplaced to create a sand pack around the well point. The borehole annular space around the tubing above the sand pack will be filled with annular seal of granular bentonite or grout.

3.1.2.4.2 Shallow Monitoring Points

If subsurface conditions permit, shallow monitoring points will be constructed of 0.75-inch OD/0.5-inch ID PVC casing and well screen to provide additional water level information. Approximately 1 meter of factory-slotted screen will be installed for each shallow monitoring point. Effective installation of the shallow monitoring points requires that the boreholes remain open upon completion of drilling. Shallow 0.5-inch ID PVC monitoring points will be installed by punching and sampling a borehole with the Geoprobe®. Upon removing the rods, the borehole depth will be measured to determine if the hole remains open. If the borehole is open, the 0.5-inch ID PVC casing and screen will be placed at the appropriate depths. The annular space around the screen will be filled with sand filter pack, and the annulus around the casing will be filled with grout or bentonite.

Temporary monitoring point screens will be constructed of flush-threaded, Schedule 40 PVC with an ID of 0.5 inch. The screens will be factory slotted, with 0.01-inch openings. Monitoring point screens will be placed to sample and provide water level information at or near the water table. Blank monitoring point casing will be constructed of Schedule 40 PVC with an ID of 0.5-inch. All monitoring point casing sections will be flush-threaded; joints will not be glued. The casing at each monitoring point will be fitted with a bottom cap and a top cap constructed of PVC.

If subsurface conditions do not permit the boreholes to stay open (i.e., the formation collapses in the hole), shallow 0.5-inch-ID PVC monitoring points may be installed using the Geoprobe®. If the installation of 0.5-inch PVC monitoring points is not possible or is impractical using the Geoprobe®, monitoring points constructed of 0.375-inch Teflon® (described in Section 3.1.2.4) will be utilized. Should 0.5-inch ID PVC shallow monitoring points not be installed, the only data lost will be the water level information for that particular location. The decision to install 0.5-inch ID PVC monitoring points will be made in the field once the open-hole stability of subsurface soils and Geoprobe® equipment can be evaluated. The field scientist will verify and record the total depth of the monitoring point, the lengths of all casing sections, and the depth to the top of all monitoring point completion materials. All lengths and depths will be measured to the nearest 0.1 foot.

3.1.2.5 Monitoring Point Completion

A number of the monitoring points will be completed at or slightly above grade, and steel protective casing will be used to protect the well points from tampering and damage. Where pavement is present, an at-grade cover will be cemented in place using concrete blended into the existing pavement. Where pavement is not present, the protective cover will be raised slightly above the ground surface with a 1-foot square concrete pad that will slope gently away from the cover to facilitate runoff during precipitation events. The number of permanent monitoring points will be determined by the Parsons ES field scientist. The completion of the monitoring points will be similar to those protecting the existing monitoring wells unless otherwise specified by Base personnel.

3.1.2.6 Monitoring Point Abandonment and Site Restoration

After monitoring point installation and sampling is complete, each site will be restored as closely as possible to its original condition. Those monitoring points not completed with an external casing will be abandoned. The PVC casing and screen or Teflon® tubing will be extracted as far as possible and discarded. While holes created by the Geoprobe® in sandy soils tend to cave in soon after extraction of the drive rod, any test holes remaining open after extraction of the casing will be sealed with bentonite chips, powder, pellets, or grout to eliminate any creation or enhancement of contaminant migration pathways to the groundwater.

Soil sampling using the Geoprobe® creates low volumes of soil waste. Waste cuttings generated will be contained in drums. Parsons ES will be responsible for sampling and characterizing the drum contents and will subcontract offbase disposal of the drums, if

necessary. Travis AFB will be responsible for providing their EPA generator identification and signing the manifest prior to disposal.

3.1.2.7 Monitoring Point Development and Records

The monitoring points will be developed prior to sampling to remove fine sediments from the portion of the formation adjacent to the well point screen. Development will be accomplished using a peristaltic pump provided by Parsons ES. The pump will be attached to the well point and water will be removed until pH, temperature, specific conductivity, and water clarity (turbidity) stabilize. Monitoring point development will occur a minimum of 24 hours prior to sampling. All development waters and purge waters will be handled as detailed in Section 3.1.2.3.

A development record will be maintained for each monitoring point. The development record will be completed in the field by the field scientist. Figure 3.5 is an example of a development record used for similar well installations. Development records will include:

- Monitoring point number;
- Date and time of development;
- Development method;
- Monitoring point depth;
- Volume of water produced;
- Description of water produced;
- Post-development water level and monitoring point depth; and
- Field analytical measurements, including pH and specific conductivity.

3.1.3 Groundwater Grab Sampling Procedures

The sampling depth and interval will be specified prior to driving the Geoprobe® pushrod into the ground. The Parsons ES field scientist will verify the sampling depth by measuring the length of each pushrod prior to insertion into the ground. A drive tip fitted with a slotted steel screen will be placed on the tip of the pushrod, and the rod will be pushed into the ground using the Geoprobe® apparatus. After reaching the desired depth, the pushrod will be raised 1 to 2 feet to expose the screen and to allow water to percolate into the end of the hollow pushrod. Water samples will be collected from water entering the downhole, slotted end of the pushrod through the screen with a peristaltic pump. The groundwater sample will be acquired as described in Section 3.2.2.

MONITORING POINT DEVELOPMENT RECORD

Page of

Job Number: 722450.27
Location: _____
Well Number: _____

Job Name: Travis AFB, California
By: _____
Measurement Datum: _____

Date: _____

Pre-Development Information

Time (Start):

Water Level:

Total Depth of Well:

Water Characteristics

Color: _____

Clear

Cloudy

Odor: None Weak

Moderate

Strong

Any Films or Immiscible Material: _____

pH: _____ Temperature(°F °C): _____

Specific Conductance (μS/cm): _____

Interim Water Characteristics

Gallons Removed:

pH:

Temperature (°F °C):

Specific Conductance(μS/cm):

Post-Development Information

Time (Finish):

Water Level:

Total Depth of Well:

Approximate Volume Removed:

Water Characteristics

Color: _____

Clear

Cloudy

Odor: None Weak

Moderate

Strong

Any Films or Immiscible Material: _____

pH: _____ Temperature(°F °C): _____

Specific Conductance (μS/cm): _____

Comments:

FIGURE 3.5
MONITORING POINT
DEVELOPMENT RECORD
North and South Gas Station
Intrinsic Remediation TS
Travis AFB, California



PARSONS
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Alameda, California

3.1.4 Monitoring Point Location and Datum Survey

The location and elevation of the well points will be surveyed soon after completion. The horizontal location will be measured relative to established Base coordinates. Horizontal coordinates will be measured to the nearest 0.1 foot. The elevation of the ground surface adjacent to the protective casing will be measured relative to the USGS MSL datum. The ground surface elevation will be measured to the nearest 0.1 foot. A top of casing datum will be measured to the nearest 0.01 foot for all monitoring points constructed of 0.5-inch PVC casing and well screen. Because water levels cannot be measured through the well point tubing, no datum elevation, such as top of casing, will be measured for monitoring points constructed of Teflon® tubing.

3.1.5 Water Level Measurements

Water levels at monitoring wells and monitoring points will be measured (where possible) within a short time period so that the water level data are comparable. The depth to water below the measurement datum will be measured to the nearest 0.01 foot using an electric water level probe.

3.2 GROUNDWATER SAMPLING

This section describes the scope of work required for collection of groundwater quality samples. Samples will be collected from all 21 existing monitoring wells (i.e., MW-135 through MW-214), up to 3 Base background monitoring wells (if appropriate for the NSGS site), and at up to 6 newly installed groundwater monitoring points and grab sample locations. A peristaltic pump with dedicated tubing will be used to collect groundwater samples. In order to maintain a high degree of QC during this sampling event, the procedures described in the following sections will be followed.

Sampling will be conducted by qualified scientists and technicians from Parsons ES who are trained in the conduct of groundwater sampling, records documentation, and chain-of-custody procedures. In addition, sampling personnel will have thoroughly reviewed this work plan prior to sample acquisition and will have a copy of the work plan available onsite for reference. The following activities will occur during groundwater sampling:

- Assembly and preparation of equipment and supplies;
- Inspection of the monitoring well/point integrity, including:
 - Protective cover, cap, and lock,
 - External surface seal and pad,

- Monitoring point stick-up, cap, and datum reference, and
 - Internal surface seal;
- Groundwater sampling, including:
 - Water level and product thickness measurements,
 - Visual inspection of sample water,
 - Monitoring point casing evacuation, and
 - Sample collection;
- Sample preservation and shipment, including:
 - Sample preparation,
 - Onsite measurement of physical parameters, and
 - Sample labeling;
- Completion of sampling records,
- Sample disposition.

Detailed groundwater sampling and sample handling procedures are presented in following sections.

3.2.1 Preparation for Sampling

All equipment to be used for sampling will be assembled and properly cleaned and calibrated (if required) prior to arriving in the field. In addition, all record-keeping materials will be gathered prior to leaving the office.

3.2.1.1 Equipment Cleaning

All portions of sampling and test equipment that will contact the sample matrix will be thoroughly cleaned before each use. This includes the Geoprobe® soil sampling tool, water level probe and cable, lifting line, test equipment for onsite use, and other equipment or portions thereof that will contact the samples. Based on the types of sample analyses to be conducted, the following cleaning protocol will be used:

- Wash with potable water and phosphate-free laboratory detergent (HP-II detergent solutions, as appropriate);
- Rinse with potable water;
- Rinse with isopropyl alcohol;

- Rinse with distilled or deionized water; and
- Air dry the equipment prior to use.

Any deviations from these procedures will be documented in the field scientist's field notebook and on the groundwater sampling record (Figure 3.6).

If precleaned disposable sampling equipment is used, the cleaning protocol specified above will not be required. Laboratory-supplied sample containers will be cleaned and sealed by the laboratory. The type of container provided and the method of container decontamination will be documented in the permanent record of the sampling event.

3.2.1.2 Equipment Calibration

As required, field analytical equipment will be calibrated according to the manufacturers' specifications prior to field use. Calibration records for field analytical equipment will be maintained by Parsons ES and field calibrations will be recorded in the field notebook. This applies to equipment used for onsite measurements of DO, pH, electrical conductivity, temperature, redox potential, sulfate, nitrate, ferrous iron (Fe^{2+}), and other field parameters listed in Table 3.1.

3.2.2 Sampling Procedures

Special care will be taken to prevent contamination of the groundwater and extracted samples. The two primary ways in which sample contamination can occur are through contact with improperly cleaned equipment and through cross-contamination due to insufficient cleaning of equipment between wells and monitoring points. To prevent such contamination, the water level probe and cable used to determine static water levels and total well depths will be thoroughly cleaned before and after field use and between uses at different sampling locations according to the procedures presented in Section 3.2.1.1.

Dedicated tubing will be used at each well or monitoring point developed, purged, and/or sampled with the peristaltic pump. Dedicated, disposable bailers may be used on the 2-inch ID existing wells. Any nondisposable bailers will be decontaminated according to procedures listed in Section 3.2.1.1. In addition to the use of properly cleaned equipment, a clean pair of new, disposable nitrile or latex gloves will be worn each time a different well or monitoring point is sampled. The following paragraphs present the procedures to be followed for groundwater sample collection from groundwater monitoring wells and monitoring points. These activities will be performed in the order presented below. Exceptions to this procedure will be noted in the field scientist's field notebook.

GROUNDWATER SAMPLING RECORD

SAMPLING LOCATION _____
SAMPLING DATE(S) _____
MONITORING WELL _____
(number)

REASON FOR SAMPLING: Regular Sampling; Special Sampling;

DATE AND TIME OF SAMPLING: _____, 19 _____ a.m./p.m.

SAMPLE COLLECTED BY: _____ of _____

WEATHER: _____

DATUM FOR WATER DEPTH MEASUREMENT (Describe): _____

MONITORING WELL CONDITION:

LOCKED: UNLOCKED

WELL NUMBER (IS - IS NOT) APPARENT

STEEL CASING CONDITION IS: _____

INNER PVC CASING CONDITION IS: _____

WATER DEPTH MEASUREMENT DATUM (IS - IS NOT) APPARENT

DEFICIENCIES CORRECTED BY SAMPLE COLLECTOR

MONITORING WELL REQUIRED REPAIR (describe): _____

Check-off

1 EQUIPMENT CLEANED BEFORE USE WITH _____

Items Cleaned (List): _____

2 PRODUCT DEPTH _____ FT. BELOW DATUM

Measured with: _____

WATER DEPTH _____ FT. BELOW DATUM

Measured with: _____

3 WATER-CONDITION BEFORE WELL EVACUATION (Describe):

Appearance: _____

Odor: _____

Other Comments: _____

4 WELL EVACUATION:

Method: _____

Volume Removed: _____

Observations: Water (slightly - very) cloudy

Water level (rose - fell - no change)

Water odors: _____

Other comments: _____

FIGURE 3.6 GROUNDWATER SAMPLING RECORD

North and South Gas Station
Intrinsic Remediation TS
Travis AFB, California



PARSONS
ENGINEERING SCIENCE, INC.

Alameda, California

GROUND WATER SAMPLING RECORD (Continued)

MONITORING WELL _____

5 []

SAMPLE EXTRACTION METHOD:

Bailer made of: _____
 Pump, type: _____
 Other, describe: _____

Sample obtained is GRAB; COMPOSITE SAMPLE

6 []

ON-SITE MEASUREMENTS:

Temp: _____ ° _____ Measured with: _____
pH: _____ Measured with: _____
Conductivity: _____ Measured with: _____
Dissolved Oxygen: _____ Measured with: _____
Redox Potential: _____ Measured with: _____
Salinity: _____ Measured with: _____
Nitrate: _____ Measured with: _____
Sulfate: _____ Measured with: _____
Ferrous Iron: _____ Measured with: _____
Other: _____

7 []

SAMPLE CONTAINERS (material, number, size):

8 []

ON-SITE SAMPLE TREATMENT:

Filtration: Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____

Preservatives added:

Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____
Method _____ Containers: _____

9 []

CONTAINER HANDLING:

Container Sides Labeled
 Container Lids Taped
 Containers Placed in Ice Chest

10 []

OTHER COMMENTS:

FIGURE 3.6 (cont'd)

GROUNDWATER SAMPLING RECORD

North and South Gas Station
Intrinsic Remediation TS
Travis AFB, California



PARSONS
ENGINEERING SCIENCE, INC.

Alameda, California

3.2.2.1 Preparation of Location

Prior to starting the sampling procedure, the area around the existing wells and new monitoring points will be cleared of foreign materials, such as brush, rocks, and debris. These procedures will prevent sampling equipment from inadvertently contacting debris around the monitoring well/point.

3.2.2.2 Water Level and Total Depth Measurements

Prior to removing any water from the monitoring well or monitoring point, the static water level will be measured. An electric water level probe will be used to measure the depth to groundwater below the datum to the nearest 0.01 foot. After measuring the static water level, the water level probe will be slowly lowered to the bottom of the monitoring well/point and the depth will be measured to the nearest 0.01 foot. If free-phase product (LNAPL) is present, the total depth of the well from installation records will be used to avoid excessive contamination of the water level probe and cord. Based on these measurements, the volume of water to be purged from the monitoring well/point will be calculated. If free-phase product is encountered, the thickness of the product will be measured with an oil/water interface probe.

3.2.2.3 Monitoring Well/Point Purging

The volume of water contained within the monitoring well/point casing at the time of sampling will be calculated, and a minimum of three times the calculated volume will be removed from the well/point. The actual volume removed from the well will be determined by stabilization of measurements for temperature, conductivity, and pH. A peristaltic pump will be used for monitoring well and monitoring point purging, depth permitting, and either a Waterra® inertial pump or a bailer will be used to purge all monitoring points for which a peristaltic pump is not practical. All purge water will be collected in containers provided by Parsons ES and disposed as detailed in Section 3.1.2.3.

If a monitoring well/point is evacuated to a dry state during purging, the monitoring well/point will be allowed to recharge, and the sample will be collected as soon as sufficient water is present in the monitoring well/point to obtain the necessary sample quantity. Sample compositing or sampling over a lengthy period by accumulating small volumes of water at different times to obtain a sample of sufficient volume will not be allowed.

3.2.2.4 Sample Extraction

Dedicated high-density polyethylene (HDPE) tubing and a peristaltic pump will be used to extract groundwater samples from monitoring wells/points whenever depth to groundwater

permits; otherwise, a Waterra® inertial pump or bailer will be used. A peristaltic pump will be used to extract groundwater samples from the grab sampling locations. Prior to sample collection, groundwater will be purged until dissolved oxygen and temperature readings have stabilized. The tubing, pump, or bailer will be gently lowered through the casing into the water to prevent splashing. The sample will be transferred directly into the appropriate sample container. The water will be carefully poured down the inner walls of the sample bottle to minimize aeration of the sample.

Sample containers will be completely filled so that no air space remains in the container. Excess water collected during sampling will be collected and disposed as outlined in Section 3.1.2.3.

3.2.3 Onsite Groundwater Parameter Measurement

As indicated in Table 3.1, many of the groundwater chemical parameters will be measured onsite by Parsons ES staff. Some of the measurements will be made with direct-reading meters, while others will be made using a HACH® portable colorimeter in accordance with specific HACH® analytical procedures. These procedures are described in the following subsections.

All glassware or plasticware used in the analyses will have been cleaned prior to sample collection by thoroughly washing with a solution of Alconox® and water, and rinsing with isopropyl alcohol and deionized water to prevent interference or cross-contamination between measurements. If concentrations of an analyte are above the range detectable by the titrimetric method, the analysis will be repeated by diluting the groundwater sample with double-distilled water until the analyte concentration falls to a level within the range of the method. All rinsate and sample reagents accumulated during groundwater analysis will be collected and disposed as outlined in Section 3.1.2.3.

3.2.3.1 Dissolved Oxygen Measurements

DO measurements will be made before and immediately following groundwater sample acquisition using a meter with a downhole oxygen sensor or a sensor in a flow-through cell. When DO measurements are taken in monitoring wells/points that have not yet been sampled, the existing monitoring wells/points will be purged until DO levels stabilize.

3.2.3.2 pH, Temperature, and Specific Conductance

Because the pH, temperature, and specific conductance of a groundwater sample can change significantly within a short time following sample acquisition, these parameters will be measured in the field in unfiltered, unpreserved, "fresh" water collected by the same

technique as the samples taken for laboratory analyses. The measurements will be made in a flow-through cell or a clean glass container separate from those intended for laboratory analysis, and the measured values will be recorded in the groundwater sampling record (Figure 3.6).

3.2.3.3 Alkalinity Measurements

Alkalinity in groundwater helps buffer the groundwater system against acids generated through both aerobic and anaerobic biodegradation processes. Alkalinity of the groundwater sample will be measured in the field by experienced Parsons ES scientists via titrimetric analysis using USEPA-approved HACH® Method 8221 (0 to 5,000 mg/L as calcium carbonate) or a similar method. Alkalinity of the groundwater sample will also be measured in the laboratory using USEPA Method 310.1.

3.2.3.4 Nitrate- and Nitrite-Nitrogen Measurements

Nitrate-nitrogen concentrations are of interest because nitrate can act as an electron acceptor during hydrocarbon biodegradation under anaerobic soil or groundwater conditions. Nitrate-nitrogen is also a potential nitrogen source for biomass formation for hydrocarbon-degrading bacteria. Nitrite-nitrogen is an intermediate byproduct in both ammonia nitrification and in nitrate reduction in anaerobic environments.

Nitrate- and nitrite-nitrogen concentrations in groundwater will be measured in the field by experienced Parsons ES scientists via colorimetric analysis using a HACH® DR/700 Portable Colorimeter. Nitrate concentrations in groundwater samples will be analyzed after preparation with HACH® Method 8039 (0 to 30.0 mg/L NO₃). Nitrite concentrations in groundwater samples will be analyzed after preparation with USEPA-approved HACH® Method 8507 (0 to 0.35 mg/L NO₂) or a similar method. Nitrate and nitrite-nitrogen samples will also be analyzed by the analytical laboratory using USEPA method 353.1.

3.2.3.5 Carbon Dioxide Measurements

The presence of free carbon dioxide dissolved in groundwater is unlikely because of carbonate buffering; however, carbon dioxide concentrations should be compared to background to determine whether they are elevated. Carbon dioxide concentrations in groundwater will be measured in the field by Parsons ES scientists via titrimetric analysis using HACH® Method 8223 (0 to 250 mg/L as CO₂).

3.2.3.6 Sulfate and Sulfide Sulfur Measurements

Sulfate in groundwater is a potential electron acceptor for fuel-hydrocarbon biodegradation in anaerobic environments, and sulfide is the byproduct of sulfate reduction. A Parsons ES scientist will measure sulfate and sulfide concentrations via colorimetric analysis with a HACH® DR/700 Portable Colorimeter after appropriate sample preparation. USEPA-approved HACH® Methods 8051 (0 to 70.0 mg/L SO₄) or similar and 8131 (0.60 mg/L S²⁻) or similar will be used to prepare samples and analyze sulfate and sulfide concentrations, respectively. Sulfate concentrations will also be analyzed by the analytical laboratory using methods E300 or SW9056.

3.2.3.7 Total Iron, Ferrous Iron, and Ferric Iron Measurements

Iron is an important trace nutrient for bacterial growth, and different states of iron can affect the redox potential of the groundwater and act as an electron acceptor for biological metabolism under anaerobic conditions. Iron concentrations will be measured in the field via colorimetric analysis with a HACH® DR/700 Portable Colorimeter after appropriate sample preparation. HACH® Method 8008 (or similar) for total soluble iron (0 to 3.0 mg/L Fe³⁺ + Fe²⁺) and HACH® Method 8146 (or similar) for ferrous iron (0 to 3.0 mg/L Fe²⁺) will be used to prepare and quantitate the samples. Ferric iron will be quantitated by subtracting ferrous iron levels from total iron levels.

3.2.3.8 Manganese Measurements

Manganese is a potential electron acceptor under anaerobic environments. Manganese concentrations will be quantitated in the field using colorimetric analysis with a HACH® DR/700 Portable Colorimeter. USEPA-approved HACH® Method 8034 (0 to 20.0 mg/L) or similar will be used for quantitation of manganese concentrations.

3.2.3.9 Redox Potential

The redox potential of groundwater is an indication of the relative tendency of a solution to accept or transfer electrons. Redox reactions in groundwater are usually biologically mediated; therefore, the redox potential of a groundwater system depends upon and influences rates of biodegradation. Redox potential can be used to provide real-time data on the location of the contaminant plume, especially in areas undergoing anaerobic biodegradation. The redox potential of a groundwater sample taken inside the contaminant plume should be somewhat less than that taken upgradient or cross-gradient from the plume.

The redox potential of a groundwater sample can change significantly within a short time following sample acquisition and exposure to atmospheric oxygen. Therefore, this parameter

will be measured in the field in a flow-through cell or in unfiltered, unpreserved, "fresh" water collected by the same technique as the samples taken for laboratory analyses. The measurements will be made as quickly as possible in a clean glass container separate from those intended for laboratory analysis.

3.3 SAMPLE HANDLING FOR LABORATORY ANALYSIS

This section describes the handling of samples from the time of sampling until the samples are delivered to the fixed-base laboratory. For this study, Evergreen Analytical Laboratories, Inc. (EAL) of Wheatridge, Colorado will provide analytical laboratory support.

3.3.1 Sample Preservation

All necessary sample containers will be provided by the laboratory and necessary chemical preservatives will be pre-placed in the sample containers. Samples will be prepared for transportation to the laboratory by placing the samples in a cooler containing ice to maintain a shipping temperature of 4 degrees centigrade (°C). Samples will be delivered to the analytical laboratory via overnight courier to ensure that the temperature remains constant and that all sample holding times are met.

3.3.2 Sample Container and Labels

Sample containers and appropriate container lids will be provided by the laboratory (see Appendix A). The sample containers will be filled as described in Section 3.2.2.4, and the container lids will be tightly closed. The sample label will be firmly attached to the container side, and the following information will be legibly and indelibly written on the label:

- Facility name;
- Sample identification;
- Sample type (e.g., groundwater, soil);
- Sampling date;
- Sampling time;
- Preservatives added;
- Sample collector's initials; and
- Requested analyses.

3.3.3 Sample Shipment

After the samples are sealed and labeled, they will be packaged for transport to the laboratory. The following packaging and labeling procedures will be followed:

- Package sample so that it will not leak, spill, or vaporize from its container;
- Cushion samples to avoid breakage; and
- Add ice to container to keep samples cool.

The packaged samples will be delivered by overnight courier to the analytical laboratory. Delivery will occur as soon as possible after sample acquisition.

3.3.4 Chain-of-Custody Control

After the samples have been collected, chain-of-custody procedures will be followed to establish a written record of sample handling and movement between the sampling site and the analytical laboratory. Each shipping container will have a chain-of-custody form completed in triplicate by the sampling personnel. One copy of this form will be kept by the sampling contractor after sample delivery to the analytical laboratory. The other two copies will become a part of the permanent record for the sample and will be returned with the sample analytical results. The chain-of-custody will contain the following information:

- Sample identification number;
- Sample collectors' printed names and signatures;
- Date and time of collection;
- Place and address of collection;
- Sample matrix;
- Chemical preservatives added;
- Analyses requested;
- Signatures of individuals involved in the chain of possession; and
- Inclusive dates of possession.

The chain-of-custody documentation will be placed inside the shipping container so that it will be immediately apparent to the laboratory personnel receiving the container, but will not be damaged or lost during transport. The shipping container will be sealed so that it will be obvious if the seal has been tampered with or broken.

3.3.5 Sampling Records

In order to provide complete documentation of the sampling event, detailed records will be maintained by the field scientist. At a minimum, these records will include the following information:

- Sample location (facility name);
- Sample identification;
- Sample location map or detailed sketch;
- Date and time of sampling;
- Sampling method;
- Field observations of
 - Sample appearance, and
 - Sample odor;
- Weather conditions;
- Water level prior to purging;
- Total monitoring well/point depth;
- Purge volume;
- Water level after purging;
- Monitoring well/point condition;
- Sampler's identification;
- Field measurements of pH, temperature, DO, and specific conductivity; and
- Any other relevant information.

Groundwater sampling information will be recorded on a groundwater sampling form. Figure 3.6 is an example of the groundwater sampling record.

3.3.6 Laboratory Analyses

Laboratory analyses will be performed on all groundwater samples and the QA/QC samples described in Section 5. The analytical methods for this sampling event were listed in Table 3.1. Prior to sampling, arrangements will be made with the analytical laboratory to provide a sufficient number of analyte-appropriate sample containers for the samples to be

collected. All containers, preservatives, and shipping requirements will be consistent with USEPA protocol or those reported in Appendix A of this plan.

Laboratory personnel will specify the necessary QC samples and prepare appropriate QC sample bottles. For samples requiring chemical preservation, preservatives will be added to containers by laboratory personnel. Containers, ice chests with adequate padding, and cooling media may be sent by the laboratory to the site.

SECTION 4

REMEDIAL OPTION EVALUATION AND TS REPORT

Upon completion of field work, the Bioplume II numerical groundwater model will be used to determine the fate and transport of fuel hydrocarbons dissolved in groundwater at the site. Based upon model predictions of contaminant concentration and distribution through time, and upon potential exposure pathways, the potential risk to human health and the environment will be assessed. If it is shown that intrinsic remediation of BTEX compounds at the site is sufficient to reduce the potential risk to human health and the environment to acceptable levels (e.g., state groundwater standards), Parsons ES will recommend implementation of the intrinsic remediation option. If intrinsic remediation is chosen, Parsons ES will prepare a site-specific, long-term monitoring plan that will specify the location of point-of-compliance monitoring wells and sampling frequencies.

If the intrinsic remediation remedial option is deemed inappropriate for use at this site, institutional controls such as groundwater or land use restrictions will be evaluated to determine if they will be sufficient to reduce the risk to human health and the environment to acceptable levels. If institutional controls are inappropriate, remedial options which could reduce risks to acceptable levels will be evaluated and the most appropriate remedial options will be recommended. Potential remedial options include, but are not limited to, free product recovery, groundwater pump and treat, enhanced biological treatment, bioventing, bioslurping, and *in situ* reactive barrier walls. The reduction in dissolved BTEX that should result from remedial activities will be used to produce a new input file for the Bioplume II model. The model will then be used to predict the BTEX plume (and risk) reduction that should result from remedial actions.

Upon completion of Bioplume II modeling and remedial option selection, a TS report detailing the results of the modeling and remedial option selection will be prepared. This report will follow the outline presented in Table 4.1 and will contain an introduction, site descriptions, identification of remediation objectives, description of remediation alternatives, an analysis of remediation alternatives, and the recommended remedial approach for each site. This report will also contain the results of the site characterization activities described herein and a description of the Bioplume II model developed for this site.

TABLE 4.1
EXAMPLE TS REPORT OUTLINE
NORTH AND SOUTH GAS STATIONS
INTRINSIC REMEDIATION TS
TRAVIS AFB, CALIFORNIA

INTRODUCTION

SITE DESCRIPTION

- Drilling, Soil Sampling, and Monitoring Well Installation
- Groundwater Sampling
- Aquifer Testing
- Surveying

PHYSICAL CHARACTERISTICS OF THE STUDY AREA

- Surface Features
- Regional Geology and Hydrogeology
- Site Geology and Hydrogeology

NATURE AND EXTENT OF CONTAMINATION

- Source of Contamination
- Soil Chemistry
- Groundwater Chemistry

GROUNDWATER MODEL

- General Overview and Model Description
- Conceptual Model Design and Assumptions
- Initial Model Setup
- Model Calibration
- Sensitivity Analysis
- Model Results
- Conclusions and Discussion

COMPARATIVE ANALYSIS OF REMEDIAL ALTERNATIVES

- Remedial Alternative Evaluation Criteria
- Factors Influencing Alternatives Development
- Brief Description of Remedial Alternatives
- Evaluation of Alternatives
- Recommended Remedial Approach

LONG-TERM MONITORING PLAN

- Overview
- Monitoring Networks for Groundwater
- Groundwater Sampling

CONCLUSIONS AND RECOMMENDATIONS

REFERENCES

APPENDICES

SECTION 5

QUALITY ASSURANCE/QUALITY CONTROL

Field QA/QC procedures will include collection of field duplicates and rinsate, field and trip blanks; decontamination of all equipment that contacts the sample medium before and after each use; use of analyte-appropriate containers; and chain-of-custody procedures for sample handling and tracking. All samples to be transferred to the analytical laboratory for analysis will be clearly labeled to indicate sample number, location, matrix (e.g., groundwater), and analyses requested. Samples will be preserved in accordance with the analytical methods to be used and will be packaged in coolers with ice to maintain a temperature of 4°C.

All field sampling activities will be recorded in a bound, sequentially paginated field notebook in permanent ink. All sample collection entries will include the date, time, sample locations and numbers, notations of field observations, and the sampler's name and signature. Field QC samples will be collected in accordance with the program described below, and as summarized in Table 5.1.

QA/QC sampling will include collection and analysis of duplicate groundwater samples, rinsate blanks, field/trip blanks, and matrix spike samples. Internal laboratory QC analyses will involve the analysis of laboratory control samples (LCSs) and laboratory method blanks (LMBs). QA/QC objectives for each of these samples, blanks, and spikes are described below.

Groundwater samples collected from monitoring wells, monitoring points, and/or with the Geoprobe® sampler should provide sufficient volume for some duplicate analyses. Sample volume requirements are detailed in Appendix A.

One rinsate sample will be collected for every 10 or fewer groundwater samples collected from existing wells and newly installed monitoring points. Because disposable bailers may be used for this sampling event, the rinsate sample may consist of a sample of distilled water poured into a new disposable bailer and subsequently transferred into a sample container provided by the laboratory. Rinsate samples will be analyzed for volatile analytes only, as shown on Table 5.1 (BTEX and TPHg).

A field blank will be collected for every 20 or fewer groundwater samples (both from groundwater monitoring point and existing groundwater monitoring well sampling events) to assess the effects of ambient conditions in the field. The field blank will consist of a sample

TABLE 5.1
QA/QC SAMPLING PROGRAM
NORTH AND SOUTH GAS STATIONS
INTRINSIC REMEDIATION TS
TRAVIS AFB, CALIFORNIA

QA/QC Sample Types	Frequency to be Collected and/or Analyzed	Analytical Methods
Duplicates/Replicates	3 Samples (10% of Groundwater Samples)	BTEX (SW8020), TPH (SW8015M)
Rinseate Blanks	3 Samples (10% of Groundwater Samples)	BTEX (SW8020), TPH (SW8015M)
Field Blanks	2 Samples (5% of Groundwater Samples)	BTEX (SW8020), TPH (SW8015M)
Trip Blanks	One per shipping cooler containing samples for volatile analyses	BTEX (SW8020), TPH (SW8015M)
Matrix Spike Samples	Once per sampling event	BTEX (SW8020), TPH (SW8015M)
Laboratory Control Sample	Once per method per medium	Laboratory Control Charts (Method Specific)
Laboratory Method Blanks	Once per method per medium	Laboratory Control Charts (Method Specific)

of distilled water poured into a laboratory-supplied sample container while sampling activities are underway. The field blank will be analyzed for volatile analytes as shown on Table 5.1 (BTEX and TPHg).

A trip blank will be analyzed to assess the effects of ambient conditions on sampling results during the transportation of samples. The trip blank will be prepared by the laboratory and will be transported inside each cooler which contains samples for BTEX or TPHg analysis. Trip blanks will be analyzed for volatile analytes as shown on Table 5.1 (BTEX and TPHg).

Matrix spikes will be prepared in the laboratory and used to establish matrix effects for samples analyzed for the volatile analytes BTEX and TPHg. LCSs and LMBs will be prepared internally by the laboratory and will be analyzed each day samples from the site are analyzed. Samples will be reanalyzed in cases where the LCS or LMB are out of the control limits. Control charts for LCSs and LMBs will be developed by the laboratory and monitored for the analytical methods used.

SECTION 6

PROJECT SCHEDULE

The following schedule is based on the time requirements of Travis AFB for permit approval and time requirements anticipated for regulatory agency reviews and approvals.

<u>EVENT</u>	<u>DATE</u>
Draft Work Plan to Travis AFB and AFCEE	18 July 1995
Comments to Draft Work Plan received from Travis AFB	27 July 1995
Comments to Draft Work Plan due from AFCEE	11 August 1995
New monitoring point locations marked by Parsons ES personnel	14 August 1995
Confirmation of Fairfield-Suisun Sewer District permit for decon/purge water disposal due from Travis AFB	18 August 1995
Comments to Draft Work Plan due to Travis AFB from RWQCB	22 August 1995
Final Work Plan to Travis AFB, AFCEE, and RWQCB	25 August 1995
Begin groundwater sampling at existing monitoring wells	28 August 1995
Complete sampling at existing monitoring wells	06 September 1995
Digging permit due from Travis AFB for new monitoring points	08 September 1995
Begin Geoprobe drilling of new monitoring points	11 September 1995
Completion of all drilling and field sampling	15 September 1995
Draft EE/CA and Remedial Option Evaluation Report to Travis AFB and AFCEE	December 1995
Final EE/CA and Remedial Option Evaluation Report to Travis AFB and AFCEE	January 1996

SECTION 7

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APPENDIX A

**CONTAINERS, PRESERVATIVES, PACKAGING,
AND SHIPPING REQUIREMENTS
FOR GROUNDWATER SAMPLES**

Appendix A - Soil Gas and Ground Water Analytical Protocol

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Soil gas	Oxygen content of soil gas	Electrochemical oxygen meter operating over the range of 0–25 percent of oxygen in the soil gas sample	The concentration of soil gas oxygen is often related to the amount of biological activity, such as the degradation of petroleum hydrocarbons; soil gas oxygen concentrations may decrease to the point where anaerobic pathways dominate	Data are used to understand the oxygen concentration gradient with depth and to determine the presence or absence of aerobic degradation processes	Each sampling round	N/A	Field
Soil gas	Carbon dioxide content of soil gas	Nondispersive infrared instrument operating over the range of approximately 0.1–15 percent	Soil gas carbon dioxide may be produced by the degradation of petroleum hydrocarbons	Data used to understand the carbon dioxide concentration gradient with depth and to infer the biological degradation of petroleum contaminants	Each sampling round	N/A	Field
Soil gas	Methane content of soil gas	Total combustible hydrocarbon meter using a platinum catalyst with a carbon trap, and operating in the low parts per million volume (ppmv) range	Methane is a product of the anaerobic degradation of petroleum hydrocarbons	Soil gas methane can be used to locate contaminated soil and to determine the presence of anaerobic processes; see discussion of data use for methane in water	Each sampling round	N/A	Field
Soil gas	Fuel hydrocarbon vapor content of soil gas	Total combustible hydrocarbon meter operating over a wide ppmv range	Soil gas hydrocarbons indicate the presence of these contaminants in the soil column	Data used to understand the petroleum hydrocarbon concentration gradient with depth and to locate the most heavily contaminated soils	Each sampling round	N/A	Field

Appendix A (Continued)

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Water	Ferrous (Fe^{+2})	Colorimetric A3500-Fe D	Field only	May indicate an anaerobic degradation process due to depletion of oxygen, nitrate, and manganese	Each sampling round	Collect 100 mL of water in a glass container; acidify with hydrochloric acid per method	Field
Water	Ferrous (Fe^{+2})	Colorimetric HACH 25140-25	Alternate method; field only	May indicate an anaerobic degradation process due to depletion of oxygen, nitrate, and manganese	Each sampling round	Collect 100 mL of water in a glass container	Field
Water	Temperature	E170.1	Field only	Well development	Each sampling round	N/A	Field
Water	Chloride	Mercuric nitrate titration A4500-Clr C	Ion chromatography (IC) method E300 or method SW9050 may also be used	General water quality parameter used as a marker to verify that site samples are obtained from the same groundwater system	Each sampling round	Collect 250 mL of water in a glass container	Field
Water	Oxygen	Dissolved oxygen meter	Refer to method A4500 for a comparable laboratory procedure	The oxygen concentration is a data input to the Biopluume model; concentrations less than 1 mg/L generally indicate an anaerobic pathway	Each sampling round	Collect 300 mL of water in biochemical oxygen demand bottles; analyze immediately; alternately, measure dissolved oxygen <i>in situ</i>	Field
Water	pH	E150.1/SW9040, direct reading meter	Protocols/Handbook methods	Aerobic and anaerobic processes are pH-sensitive	Each sampling round	Collect 100–250 mL of water in a glass or plastic container; analyze immediately	Field
Water	Conductivity	E120.1/SW9050, direct reading meter	Protocols/Handbook methods	General water quality parameter used as a marker to verify that site samples are obtained from the same groundwater system	Each sampling round	Collect 100–250 mL of water in a glass or plastic container	Field

Appendix A (Continued)

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Water	Alkalinity	A22320, litrimetric; E310.2, colorimetric	Handbook method	General water quality parameter used (1) as a marker to verify that all site samples are obtained from the same groundwater system and (2) to measure the buffering capacity of groundwater	Each sampling round	Collect 250 mL of water in a glass or plastic container; analyze within 6 hours	Field
Water	Nitrate (NO ₃ ⁻)	IC method E300 or method SW9056; colorimetric, method E353.2	Method E300 is a Handbook method; method SW9056 is an equivalent procedure	Substrate for microbial respiration if oxygen is depleted	Each sampling round	Collect up to 40 mL of water in a glass or plastic container; cool to 4°C; analyze within 48 hours	Fixed-base
Water	Sulfate (SO ₄ ²⁻)	IC method E300 or method SW9056	Method E300 is a Handbook method; method SW9056 is an equivalent procedure	Substrate for anaerobic microbial respiration	Each sampling round	Collect up to 40 mL of water in a glass or plastic container; cool to 4°C	Fixed-base
Water	Sulfate (SO ₄ ²⁻)	HACH Sulfiva Ver 4 method	Photometric	Substrate for anaerobic microbial respiration	Each sampling round	Collect up to 40 mL of water in a glass or plastic container; cool to 4°C	Field
Water	Redox potential	A2580 B	Measurements are made with electrodes; results are displayed on a meter; samples should be protected from exposure to atmospheric oxygen	The redox potential of groundwater influences and is influenced by the nature of the biologically mediated degradation of contaminants; the redox potential of groundwater may range from more than 200 mV to less than -400 mV	Each sampling round	Collect 100–250 mL of water in a glass container, filling container from bottom; analyze immediately	Field

Appendix A (Continued)

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Water	Dissolved sulfide (S^{2-})	Hach Model HS-C test kit	Procedure uses reagent-impregnated test strips to determine sulfide species (except insoluble metal sulfides) in the 0 to 5 mg/L range. Method published and used by the U.S. Environmental Protection Agency (EPA) Robert S. Kerr Laboratory	Product of sulfate-based anaerobic microbial respiration; analyze in conjunction with sulfate analysis	Each sampling round	Collect 100 mL of water in a glass container; analyze immediately	Field
Water	Methane; carbon dioxide	RSK SOP-114 modified to analyze water samples for methane and carbon dioxide by headspace sampling with dual thermal conductivity and flame ionization detection (also, see reference in note 10)	The presence of methane suggests BTEX degradation via an anaerobic pathway utilizing carbon dioxide (carbonate) as the electron acceptor (methanogenesis); a redox potential measurement of less than -200 mV could be indicative of methanogenesis and should be followed by the analysis referenced here; the presence of free carbon dioxide dissolved in groundwater is unlikely because of the carbonate buffering system of water, but if detected, the carbon dioxide concentrations should be compared with background to determine whether they are elevated; elevated concentrations of carbon dioxide could indicate an aerobic mechanism for bacterial degradation of petroleum	Each sampling round	Collect water samples in 40 mL volatile organic analysis (VOA) vials with butyl gray/Teflon-lined caps; cool to 4°C	Fixed-base	

Appendix A (Continued)

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Water	Carbon dioxide	H ₄ ACH	Titrimetric; alternate method	The presence of free carbon dioxide dissolved in groundwater is unlikely because of the carbonate buffering system of water, but if detected, the carbon dioxide concentrations should be compared with background to determine whether they are elevated; elevated concentrations of carbon dioxide could indicate an aerobic mechanism for bacterial degradation of petroleum	Each sampling round	N/A	Field
	Aromatic hydrocarbons (BTEX, trimethylbenzene isomers)	Purge and trap GC method SW8020	Handbook method; analysis may be extended to higher molecular weight alkyl benzenes	Method of analysis for BTEX, which is the primary target analyte for monitoring natural attenuation; BTEX concentrations must also be measured for regulatory compliance; method can be extended to higher molecular weight alkyl benzenes; trimethylbenzenes are used to monitor plume dilution if degradation is primarily anaerobic	Each sampling round	Collect water samples in a 40 mL VOA vial; cool to 4°C; add hydrochloric acid to pH 2	Fixed-base

Appendix A (Continued)

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Water	Total hydrocarbons, volatile and extractable	GC method SW8015 [modified]	Handbook method; reference is the California LUFT manual	Data used to monitor the reduction in concentrations of total fuel hydrocarbons (in addition to BTEX) due to natural attenuation; data also used to infer presence of an emulsion or surface layer of petroleum in water sample, as a result of sampling	One time per year or as required by regulations	Volatile hydrocarbons—collect water samples in a 40 mL VOA vial; cool to 4°C; add hydrochloric acid to pH 2 Extractable hydrocarbons—collect 1 L of water in a glass container; cool to 4°C; add hydrochloric acid to pH 2	Fixed-base
Water	Polycyclic aromatic hydrocarbons (PAHs) (optional)	GC/mass spectroscopy method SW8270; high-performance liquid chromatography method SW8310	Analysis needed only for several samples per site	PAHs are components of fuel and are typically analyzed for regulatory compliance; data on their concentrations are not used currently in the evaluation of natural attenuation	At initial sampling and at site closure or as required by regulations	Collect 1 L of water in a glass container; cool to 4°C	Fixed-base
Water	Total fuel carbon (optional)	Purge and trap GC method SW8020 modified to measure all volatile aromatic hydrocarbons present in the sample	A substitute method for measuring total volatile hydrocarbons; reports amount of fuel as carbon present in the sample; method available from the U.S. EPA Robert S. Kerr Laboratory	Data used to monitor the reduction in concentrations of total fuel hydrocarbons (in addition to BTEX) due to natural attenuation	At initial sampling and at site closure	Collect 40 mL of water in glass vials with Teflon-lined caps; add sulfuric acid to pH 2; cool to 4°C	Fixed-base

Appendix A (Continued)

Matrix	Analysis	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Water	Dissolved organic carbon (DOC) (optional)	A5310 C	An oxidation procedure whereby carbon dioxide formed from DOC is measured by an infrared spectrometer. The minimum detectable amount of DOC is 0.05 mg/L	An indirect index of microbial activity	Each sampling round	Collect 100 mL of water in an amber glass container with Teflon-lined cap; preserve with sulfuric acid to pH less than 2; cool to 4°C	Fixed-base

Appendix A (Concluded)

NOTES:

1. "HACH" refers to the HACH Company catalog, 1990.
2. "A" refers to *Standard Methods for the Examination of Water and Wastewater*, 18th edition, 1992.
3. "E" refers to *Methods for Chemical Analysis of Water and Wastes*, U.S. Environmental Protection Agency, March 1979.
4. "Protocols" refers to the AFCEE Environmental Chemistry Function *Installation Restoration Program Analytical Protocols*, 11 June 1992.
5. "Handbook" refers to the AFCEE *Handbook to Support the Installation Restoration Program (IRP) Remedial Investigations and Feasibility Studies (RI/FS)*, September 1993.
6. "SW" refers to the *Test Methods for Evaluating Solid Waste, Physical, and Chemical Methods*, SW-846, U.S. Environmental Protection Agency, 3rd edition, 1986.
7. "ASTM" refers to the *American Society for Testing and Materials*, current edition.
8. "RSK SOP" refers to *Robert S. Kerr Environmental Protection Agency Laboratory Standard Operating Procedure*.
9. "LUFT" refers to the state of California *Leaking Underground Fuel Tank Field Manual*, 1988 edition.
10. *International Journal of Environmental Analytical Chemistry*, Volume 36, pp. 249-257, "Dissolved Oxygen and Methane in Water by a Gas Chromatography Headspace Equilibration Technique," by D. H. Campbell, J. T. Wilson, and S. A. Vandegrift.

APPENDIX B

**SOIL AND GROUNDWATER ANALYTICAL
RESULTS FROM STAGE 1 INVESTIGATION**

Table B.1

Soil Contaminant Concentrations at
South Gas Station, Travis AFB, California

Boring (Well)	Depth (ft bgs)	Purgeable Petroleum HC						Extractable Petroleum HC						Purgeable Aromatics						Other	
		SW5030/SW8015			SW3550/SW8015			SW8020			1,2-Dichloro-1,4-Dichloro benzene			1,2-Dichloro-3-Dichloro benzene			DHS/LUFT		DHS-AB1803		
Method:	Analyte:	TPH-u	TPH-g	TPH-g	TPH-d1	TPH-d2	TPH-if	Benzene	Toluene	Ethyl-benzene	Xylenes	Total benzene	Chloro-benzene	1,2-Dichloro-3-Dichloro benzene	Organic Lead	1,2-Dibromo-ethane					
concentrations in mg/kg																					
SB 477 (MW-136)	8	NA	NA	NA	NA	NA	NA	0.0013	0.035	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA		
SB 479 (MW-141)	11	NA	NA	NA	NA	NA	NA	0.0046	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA		
SB 480	12	4.0*	4.0*	4.0*	520	2600	610	2900	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA		
SB 481	13	290	960	NA	NA	NA	0.27	0.009	0.018	0.11	NA	NA	NA	NA	NA	NA	NA	NA	NA		
SB 482 (MW-137)	14 (14(dup))	14*	1600	14*	11	72	24	120	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA		
SB 483 (MW-138)	15	4.0*	150	92	24	180	64	330	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA		
SB 484	16	18	290	11	0.14	0.18	0.22	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA		
SB 483 (MW-138)	17	11	27	0.43	0.43	0.43	0.27	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA		
SB 482 (MW-137)	14	14	3.40	0.89	5.1	8.80	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA		
SB 484	18	20	0.69	0.65	0.69	0.65	0.65	0.12	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA		
SB 483 (MW-138)	19	13	27	0.68	0.68	0.68	0.68	0.10	0.23	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA		
SB 484	21	21	0.73	0.84	0.87	0.86	0.94	0.086	0.094	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA		

LEGEND

- HC : Hydrocarbons
- bgs : below ground surface
- ND : not detected (detection limits will vary depending upon dilution factor used)
- NA : not analyzed
- (dup) : duplicate
- : Detected under detection limit

Table B.2
Groundwater Contaminant Concentrations at
South Gas Station, Travis AFB, California

Method:	Purgeable Petroleum HC		Extractable Petroleum HC		Purgeable Aromatics		Other	
	SW5030/SW8015	SW3510/SW8015			E602	DHS/LUFT	DHS-ABI803	
Analyte:	TPH-u	TPH-g	TPH-d1	TPH-d2	TPH-if	Benzene	Ethyl-benzene	1,2-Dibromo-ethane
Well	concentrations in $\mu\text{g/L}$							
MW-136								
MW-137		980				71	71	120
MW-138	45,000	26,000				3,000	2,400	900
MW-139	93,000	24,000				750	1,800	470*
MW-141	230,000	9,800,000				54,000	91,000	6,600
MW-141(dup)	270,000	6,500,000				16,000	33,000	11,000
								50,000

LEGEND

HC : Hydrocarbons	TPH-u : Unknown total hydrocarbons
	: not detected (detection limits will vary depending upon dilution factor used)
	: not analyzed
(dup)	: duplicate
*	: Detected under detection limit

Table B.3
Soil Contaminant Concentrations at
North Gas Station, Travis AFB, California

Method:	Purgeable Petroleum HC				Extractable Petroleum HC				Purgeable Aromatics				Other		
	SW5030/SW8015				SW3550/SW8015				SW8020				DHS/LUFT	Organic	Lead
Analyte:	TPH-u	TPH-g	TPH-d1	TPH-d2	TPH-u	TPH-g	TPH-d1	TPH-d2	Benzene	Toluene	Ethyl-benzene	Xylenes			
concentrations in mg/kg															
Boring	Depth (ft bgs)														
SB 475	10	NA	NA	NA	NA	NA	NA	NA	0.0018	0.072	0.0016	0.016			
	13	NA	NA	NA	NA	NA	NA	NA	1.1	3.1	2.3	15			
	14	NA	NA	NA	NA	NA	NA	NA	0.019	0.094	0.094	0.110			
SB 476	9	NA	NA	NA	NA	NA	NA	NA	0.019	0.094	0.094	0.110			
	31	NA	NA	NA	NA	NA	NA	NA	0.019	0.30	0.30	0.110			
	41	NA	NA	NA	NA	NA	NA	NA	0.019	0.10	0.10	0.074			
SB 478	11	NA	NA	NA	NA	NA	NA	NA	0.013	0.074	0.074	0.074			
	12	NA	NA	NA	NA	NA	NA	NA	0.013	0.074	0.074	0.074			
	15	NA	NA	NA	NA	NA	NA	NA	0.013	0.074	0.074	0.074			

LEGEND

HC	: Hydrocarbons	TPH-u	: Unknown total hydrocarbons
bgs	: below ground surface	TPH-g	: Total petroleum hydrocarbons as gasoline
ND	: not detected (detection limits will vary depending upon dilution factor used)	TPH-d1	: Total petroleum hydrocarbons as #1 diesel
NA	: not analyzed	TPH-d2	: Total petroleum hydrocarbons as #2 diesel
(dup)	: duplicate	TPH-jf	: Total petroleum hydrocarbons as jet fuel

anl. meth. unk

SOURCE : Roy F. Weston, Inc., 1991

06/24/95

Table B.4
Groundwater Contaminant Concentrations at
North Gas Station, Travis AFB, California

Method:	Purgeable Petroleum HC		Extractable Petroleum Hydrocarbons		Purgeable Aromatics		Other					
	SW5030/SW8015	SW3510/SW8015	E602	DHS/LUFT	DHS-AB1803							
Analyte:	TPH-u	TPH-g	TPH-g	TPH-d1	TPH-d2	TPH-if	Benzene	Ethyl-benzene	Toluene	Xylenes	Organic Lead	1,2-Dibromo-ethane
Well												
MW-135		49,000	20,000					1,110	430	1,200	5,100	
MW-140												

<i>concentrations in $\mu\text{g/L}$</i>												
<i>LEGEND</i>												
HC	: Hydrocarbons	TPH-u	: Unknown total hydrocarbons									
(■)	: not detected (detection limits will vary depending upon dilution factor used)	TPH-g	: Total petroleum hydrocarbons as gasoline									
(dup)	: duplicate	TPH-d1	: Total petroleum hydrocarbons as #1 diesel									
SOURCE: Weston, June 1991		TPH-d2	: Total petroleum hydrocarbons as #2 diesel									
		TPH-if	: Total petroleum hydrocarbons as jet fuel									

APPENDIX C

WELL CONSTRUCTION SUMMARY AND SOIL BORING LOGS FROM PREVIOUS INVESTIGATIONS

Table C.1
Monitoring and Extraction Well Construction Summary
North and South Gas Stations, Travis AFB, California

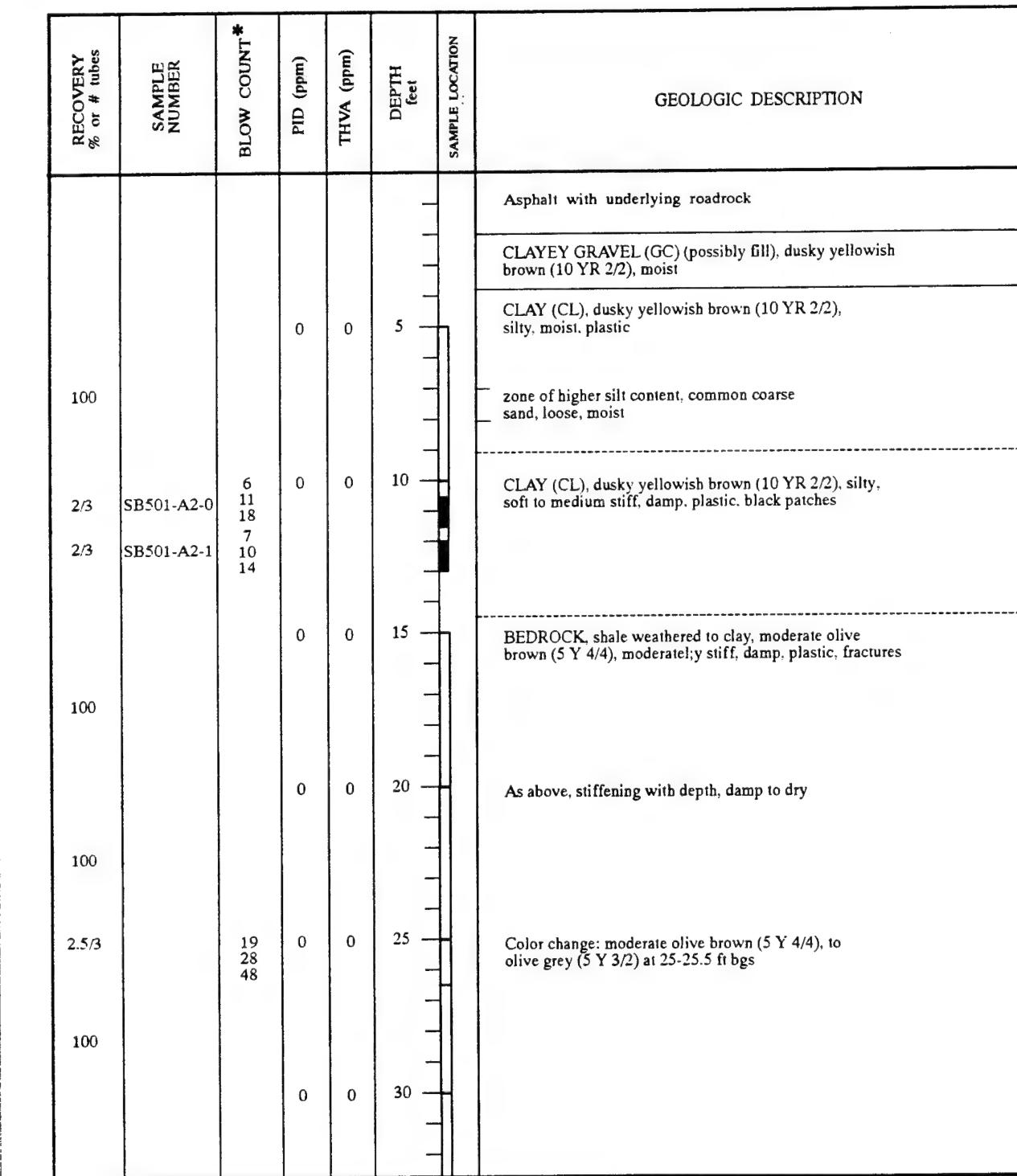
Well ID	Date Completed	Casing Depth (feet bgs)	Screen Interval ¹ (feet bgs)	Well Screen Backfill ² (feet bgs)	Bentonite Interval (feet bgs)	Grout Interval (feet bgs)
MW201	6/17/94	21.73	9.73 - 20.73	8.0 - 22.0	5.0 - 8.0	1.0 - 5.0
MW202	7/1/94	25.58	10.58 - 24.58	8.0 - 26.0	5.0 - 8.0	1.0 - 5.0
MW203	6/13/94	21.66	9.66 - 21.16	8.0 - 22.0	5.0 - 8.0	1.0 - 5.0
MW204	6/29/94	17.24	12.24 - 16.24	9.5 - 17.74	6.5 - 9.5	1.0 - 6.5
MW205	6/15/94	18.58	13.58 - 17.58	11.0 - 19.0	8.0 - 11.0	1.0 - 8.0
MW206	6/14/94	19.96	9.96 - 18.96	8.0 - 20.0	5.0 - 8.0	1.0 - 5.0
MW207	6/16/94	20.45	10.45 - 19.45	8.0 - 20.5	5.0 - 8.0	1.0 - 5.0
MW208	6/30/94	25.63	15.63 - 24.63	13.0 - 26.0	10.0 - 13.0	1.0 - 10.0
MW209	6/20/94	23.62	8.62 - 22.62	6.0 - 24.12	3.0 - 6.0	1.0 - 3.0
MW210	6/30/94	22.78	7.78 - 21.78	5.7 - 23.5	2.5 - 5.7	1.0 - 2.5
MW211	12/19/94	20.20	10.20 - 19.20	6.6 - 20.5	4.0 - 6.6	1.0 - 4.0
MW212	12/20/94	22.41	7.41 - 21.41	5.0 - 23.0	3.0 - 5.0	1.0 - 3.0
MW213	12/20/94	17.61	7.61 - 16.61	5.5 - 18.0	2.5 - 5.5	1.0 - 2.5
MW214	12/20/94	17.76	7.76 - 16.76	5.0 - 18.0	2.0 - 5.0	1.0 - 2.0
EW1	12/21/94	22.10	7.10 - 21.10	5.5 - 23.0 ³	2.5 - 5.5	1.0 - 2.5
EW2	12/22/94	21.99	6.99 - 20.99	5.5 - 23.0 ³	2.5 - 5.5	1.0 - 2.5

Notes:

- 1) Screen interval slot size = 0.01 inch for all wells
- 2) Well screen backfill consists of Monterey sand #2/16
- 3) Well screen backfill consists of Monterey sand #1/20

BORING NUMBER: SB501

PROJECT NUMBER:	723097	PROJECT NAME:	Travis AFB NSGS
CLIENT:	AFCEE	DRILLER:	Gregg Drilling, Inc.
LOCATION:	IRPIMS Site 22	DRILLING METHOD:	Hollow-stem Auger
	North and South Gas Stations		
GEOLOGIST:	H. Pietropaoli	HOLE DIAMETER:	6.5 inches
COMPLETION DATE:	6/17/94	TOTAL DEPTH:	35 feet below ground surface



* - Non-standard blow count; 2.5 inch OD sampler.

▽ - First encountered groundwater.

--- - Contact approximately located.

■ - Stainless-steel tube sample submitted for laboratory analysis.

NR - Not Recorded

□ - Drive or continuous core sample.

nsg1

BORING NUMBER: SB501

PROJECT NUMBER: 723097	PROJECT NAME: Travis AFB NSGS
CLIENT: AFCEE	DRILLER: Gregg Drilling, Inc.
LOCATION: IRPIMS Site 22	DRILLING METHOD: Hollow-stem Auger
North and South Gas Stations	
GEOLOGIST: H. Pietropaoli	HOLE DIAMETER: 6.5 inches
COMPLETION DATE: 6/17/94	TOTAL DEPTH: 35 feet below ground surface

RECOVERY % or # tubes	SAMPLE NUMBER	BLOW COUNT*	PID (ppm)	THVA (ppm)	DEPTH feet	SAMPLE LOCATION	GEOLOGIC DESCRIPTION	
							35	T.D. 35.0'
80							BEDROCK as above with patches of light gray unweathered rock	

* - Non-standard blow count: 2.5 inch OD sampler.

▽ - First encountered groundwater.

---- - Contact approximately located.

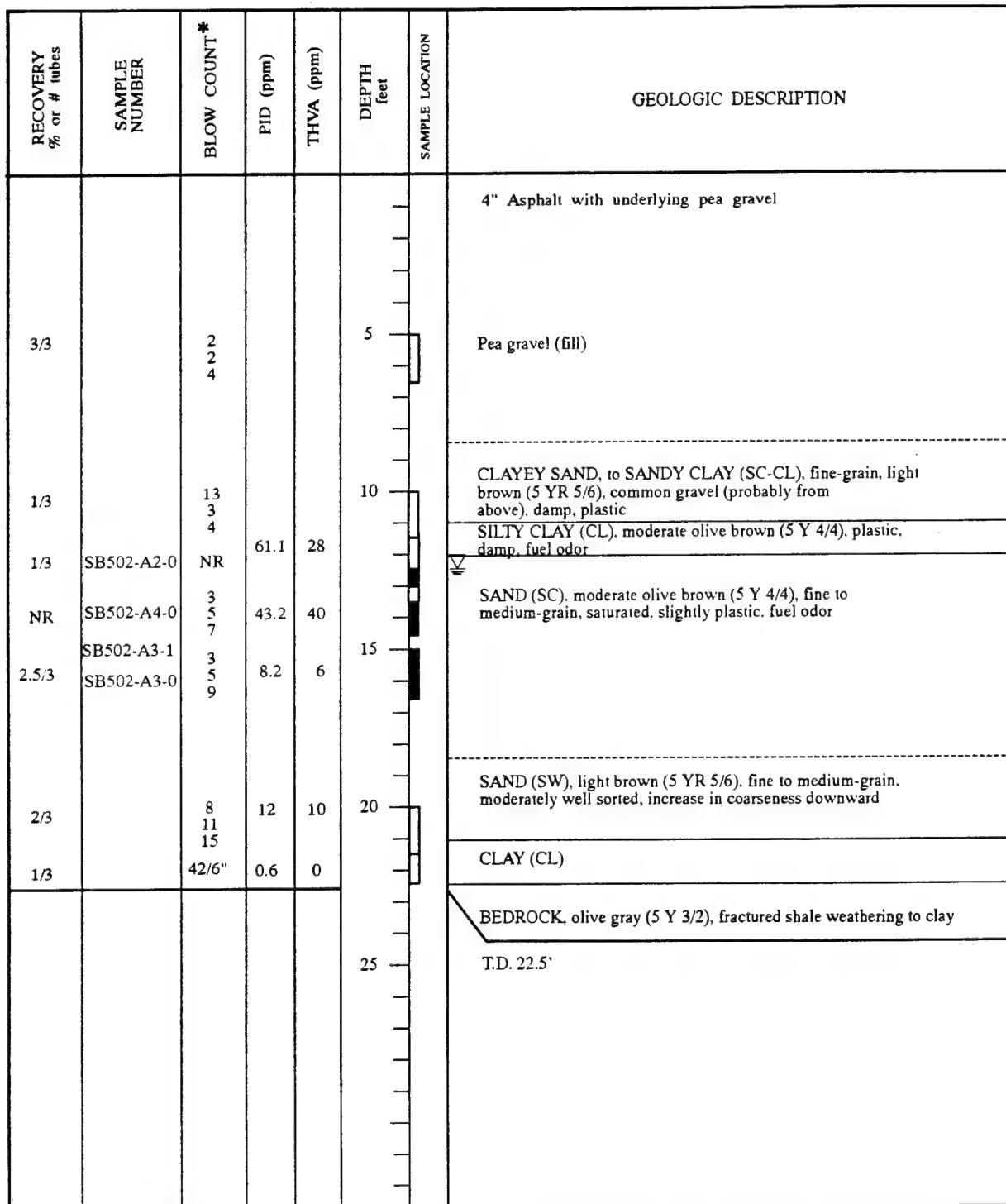
■ - Stainless-steel tube sample submitted for laboratory analysis.

NR - Not Recorded

□ - Drive or continuous core sample.

BORING NUMBER: SB502

PROJECT NUMBER:	723097	PROJECT NAME:	Travis AFB NSGS
CLIENT:	AFCEE	DRILLER:	Gregg Drilling, Inc.
LOCATION:	IRPIMS Site 22 North and South Gas Stations	DRILLING METHOD:	Hollow-stem Auger
GEOLOGIST:	H. Pietropaoli	HOLE DIAMETER:	6.5 inches
COMPLETION DATE:	6/20/94	TOTAL DEPTH:	22.5 feet below ground surface

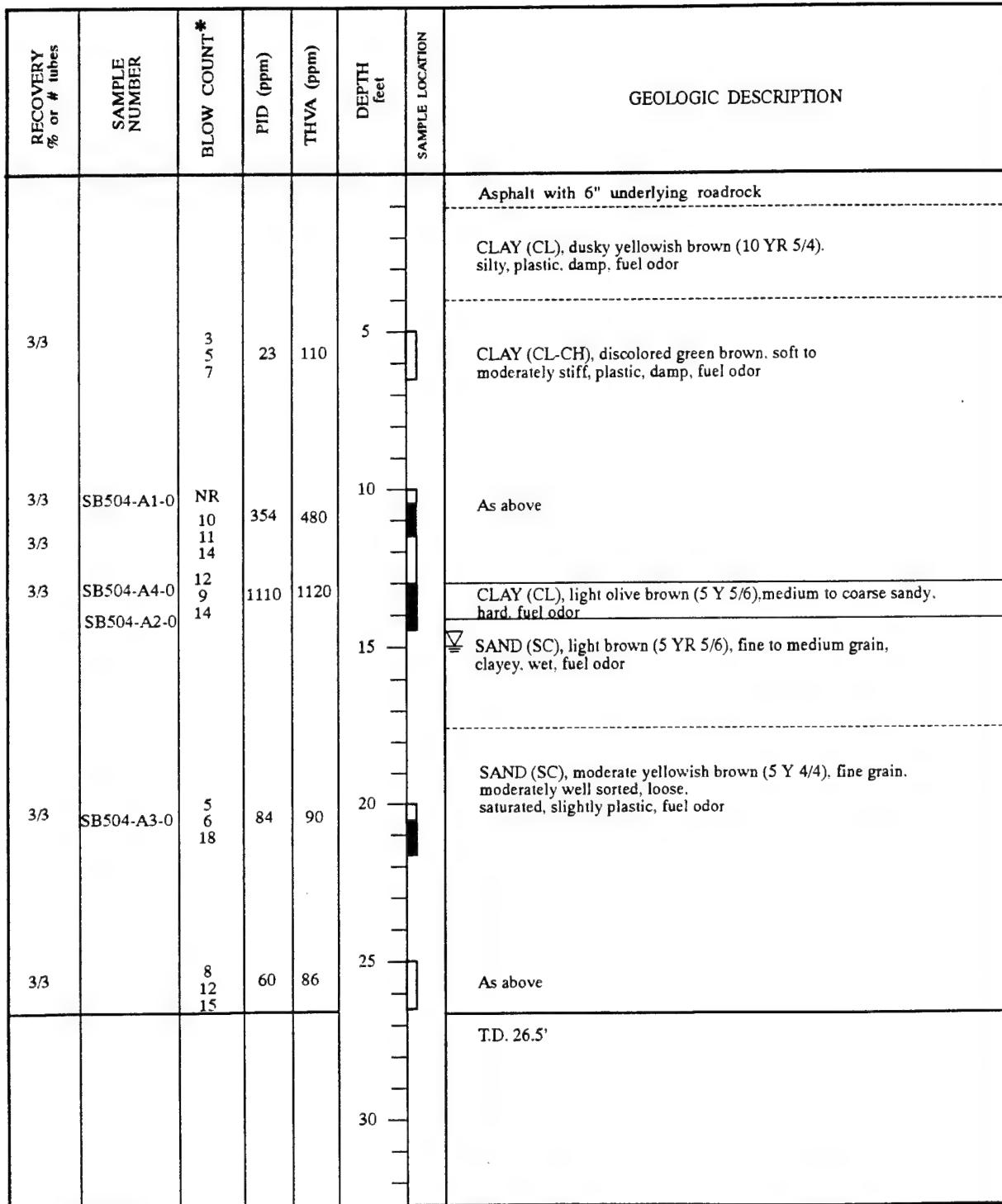


* - Non-standard blow count; 2.5 inch OD sampler.
 ▽ - First encountered groundwater.
 ---- - Contact approximately located.

■ - Stainless-steel tube sample submitted for laboratory analysis.
 NR - Not Recorded
 □ - Drive or continuous core sample.

BORING NUMBER: SB504

PROJECT NUMBER:	723097	PROJECT NAME:	Travis AFB NSGS
CLIENT:	AFCEE	DRILLER:	Gregg Drilling, Inc.
LOCATION:	IRPIMS Site 22	DRILLING METHOD:	Hollow-stem Auger
	North and South Gas Stations		
GEOLOGIST:	H. Pietropaoli	HOLE DIAMETER:	6.5 inches
COMPLETION DATE:	6/14/94	TOTAL DEPTH:	26.5 feet below ground surface



* - Non-standard blow count: 2.5 inch OD sampler.

▽ - First encountered groundwater.

---- - Contact approximately located.

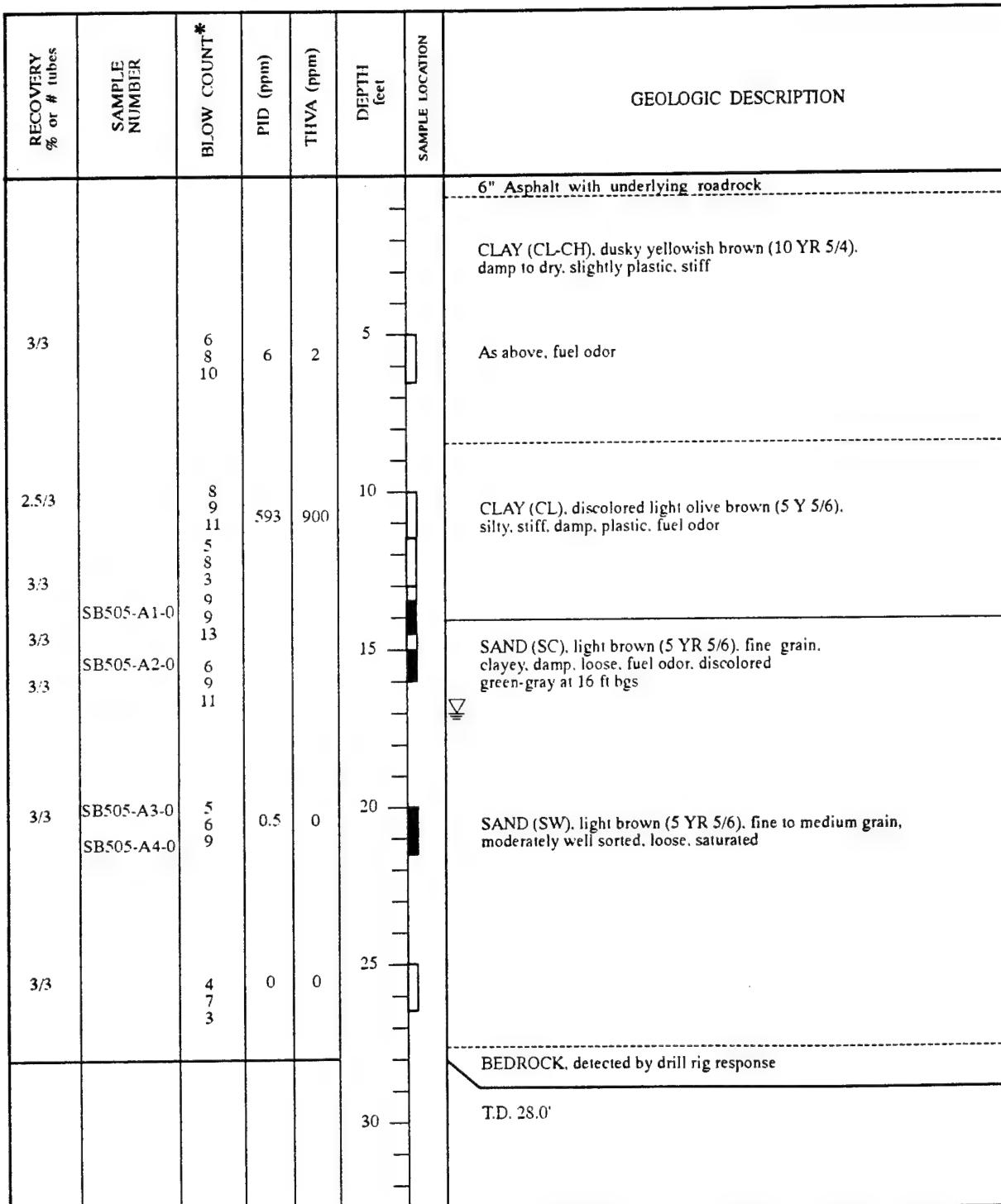
■ - Stainless-steel tube sample submitted for laboratory analysis.

NR - Not Recorded

□ - Drive or continuous core sample.

BORING NUMBER: SB505

PROJECT NUMBER:	723097	PROJECT NAME:	Travis AFB NSGS
CLIENT:	AFCEE	DRILLER:	Gregg Drilling, Inc.
LOCATION:	IRPIMS Site 22 North and South Gas Stations	DRILLING METHOD:	Hollow-stem Auger
GEOLOGIST:	H. Pietropaoli	HOLE DIAMETER:	6.5 inches
COMPLETION DATE:	6/14/94	TOTAL DEPTH:	28 feet below ground surface

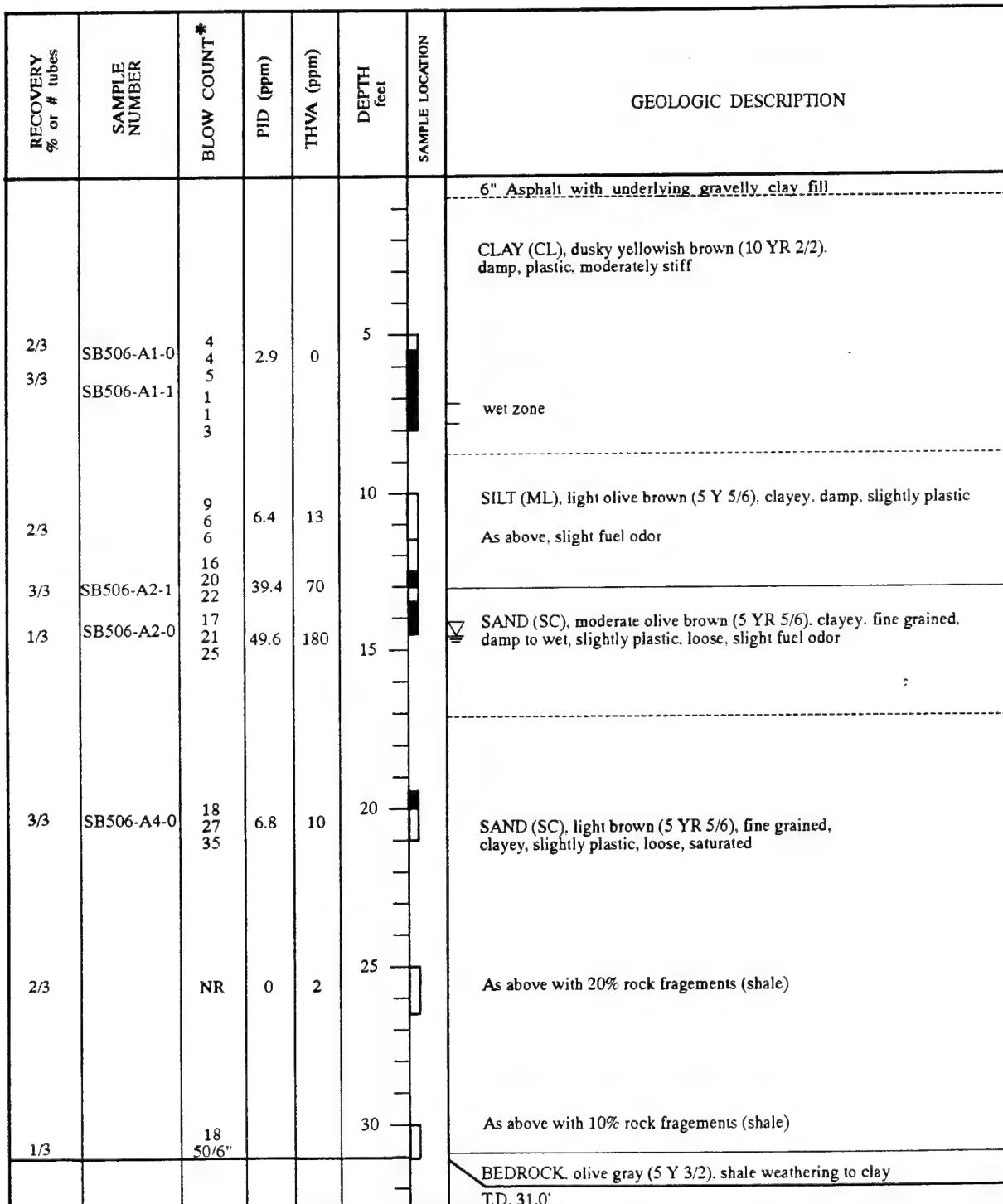


* - Non-standard blow count: 2.5 inch OD sampler.
 ▽ - First encountered groundwater.
 ---- - Contact approximately located.

■ - Stainless-steel tube sample submitted for laboratory analysis.
 NR - Not Recorded
 □ - Drive or continuous core sample.

BORING NUMBER: SB506

PROJECT NUMBER:	723097	PROJECT NAME:	Travis AFB NSGS
CLIENT:	AFCEE	DRILLER:	Gregg Drilling, Inc.
LOCATION:	IRPIMS Site 22 North and South Gas Stations	DRILLING METHOD:	Hollow-stem Auger
GEOLOGIST:	H. Pietropaoli		
COMPLETION DATE:	6/16/94	HOLE DIAMETER:	6.5 inches
		TOTAL DEPTH:	31.0 feet below ground surface

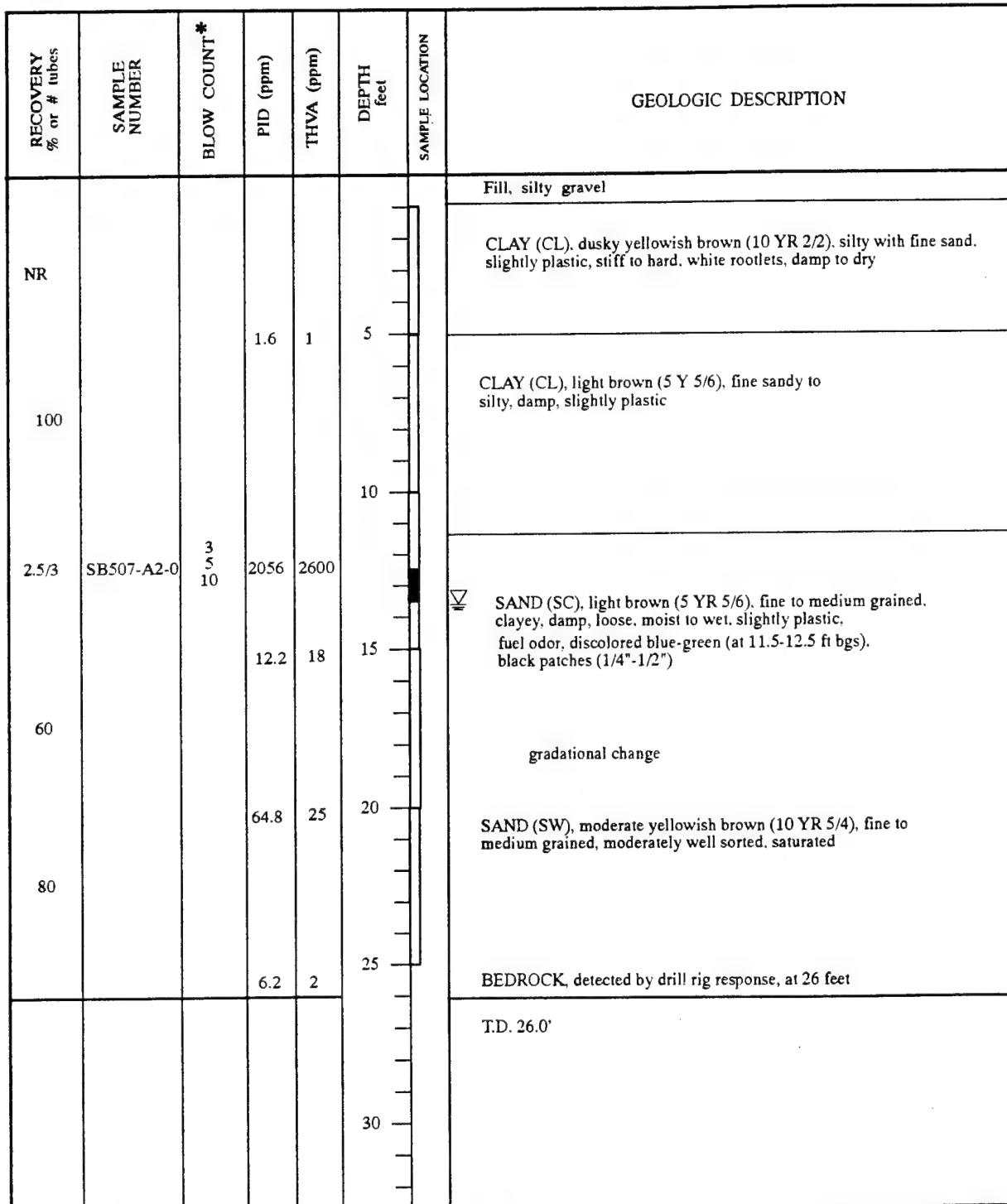


* - Non-standard blow count: 2.5 inch OD sampler.
 - First encountered groundwater.
 ---- - Contact approximately located.

- Stainless-steel tube sample submitted for laboratory analysis.
 NR - Not Recorded - Drive or continuous core sample.

BORING NUMBER: SB507

PROJECT NUMBER:	723097	PROJECT NAME:	Travis AFB NSGS
CLIENT:	AFCEE	DRILLER:	Gregg Drilling, Inc.
LOCATION:	IRPIMS Site 22 North and South Gas Stations	DRILLING METHOD:	Hollow-stem Auger
GEOLOGIST:	H. Pietropaoli	HOLE DIAMETER:	6.5 inches
COMPLETION DATE:	6/13/94	TOTAL DEPTH:	26 feet below ground surface



* - Non-standard blow count: 2.5 inch OD sampler.

▽ - First encountered groundwater.

---- - Contact approximately located.

■ - Stainless-steel tube sample submitted for laboratory analysis.

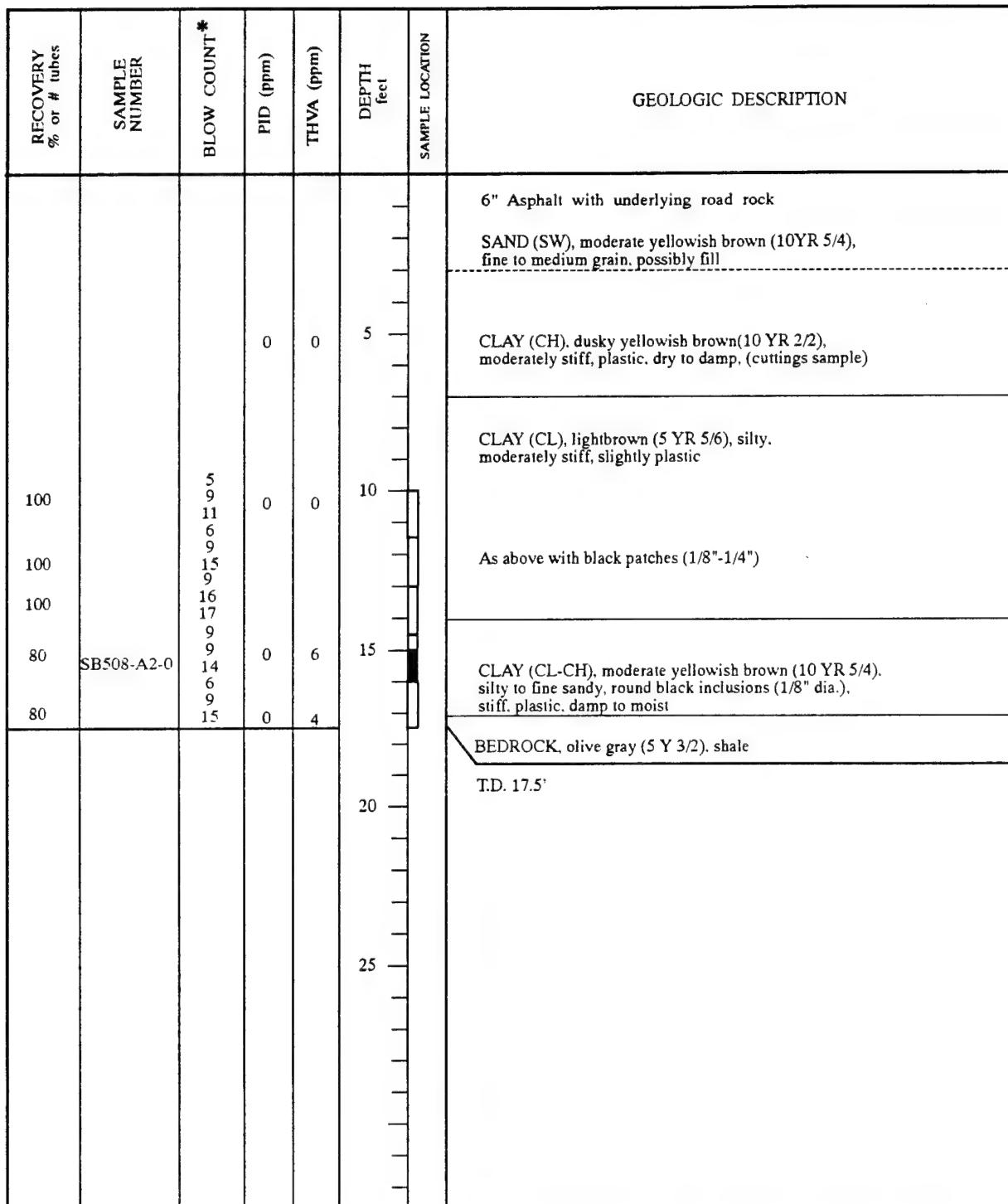
NR - Not Recorded

□ - Drive or continuous core sample.

bsg7

BORING NUMBER: SB508

PROJECT NUMBER:	723097	PROJECT NAME:	Travis AFB NSGS
CLIENT:	AFCEE	DRILLER:	Gregg Drilling, Inc.
LOCATION:	IRPIMS Site 22 North and South Gas Stations	DRILLING METHOD:	Hollow-stem Auger
GEOLOGIST:	H. Pietropaoli	HOLE DIAMETER:	6.5 inches
COMPLETION DATE:	6/15/94	TOTAL DEPTH:	17.5 feet below ground surface



* - Non-standard blow count: 2.5 inch OD sampler.

▽ - First encountered groundwater.

---- - Contact approximately located.

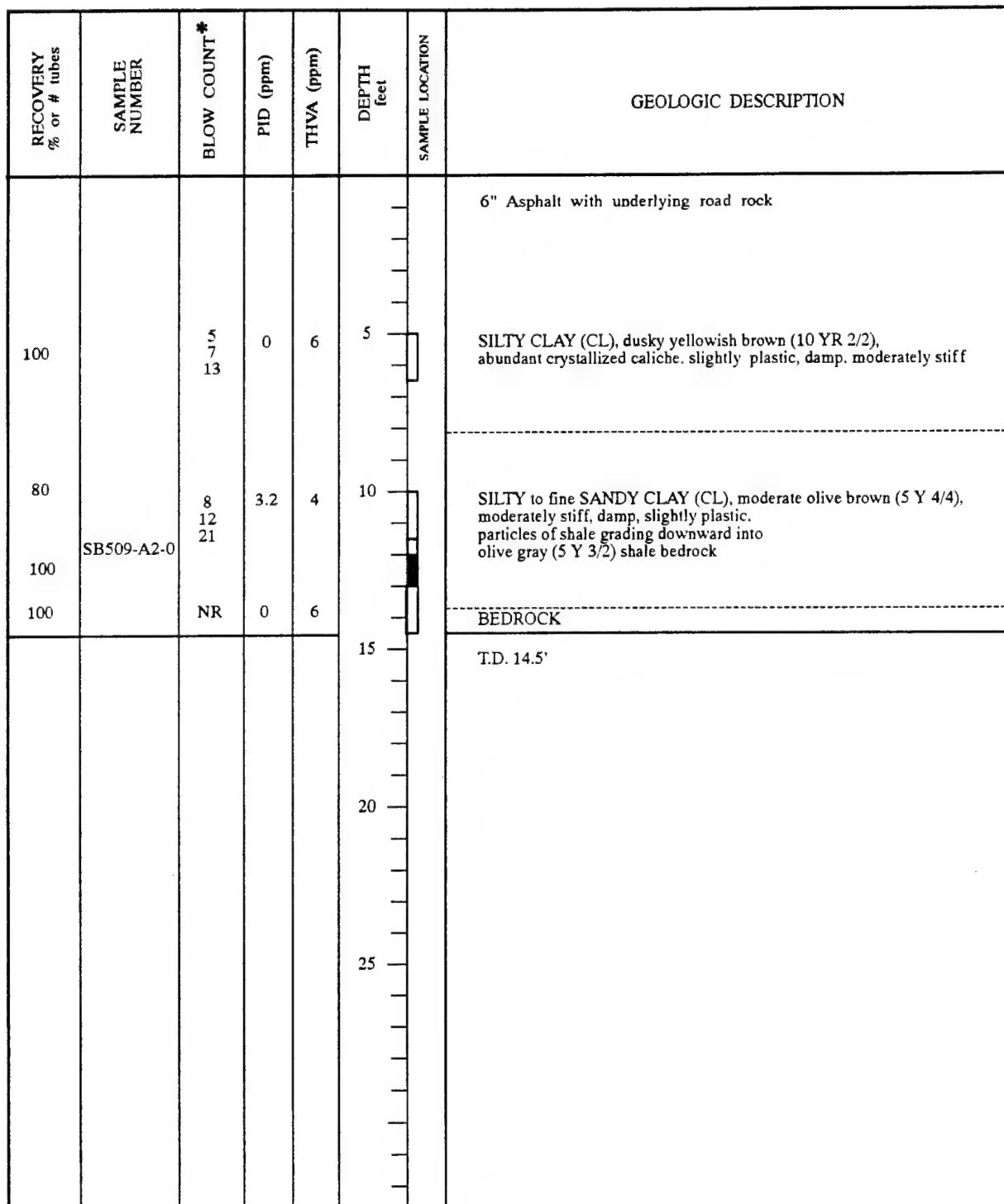
■ - Stainless-steel tube sample submitted for laboratory analysis.

NR - Not Recorded

□ - Drive or continuous core sample.

BORING NUMBER: SB509

PROJECT NUMBER:	723097	PROJECT NAME:	Travis AFB NSGS
CLIENT:	AFCEE	DRILLER:	Gregg Drilling, Inc.
LOCATION:	IRPIMS Site 22 North and South Gas Stations	DRILLING METHOD:	Hollow-stem Auger
GEOLOGIST:	H. Pietropaoli	HOLE DIAMETER:	6.5 inches
COMPLETION DATE:	6/15/94	TOTAL DEPTH:	14.5 feet below ground surface



* - Non-standard blow count; 2.5 inch OD sampler.

▽ - First encountered groundwater.

---- - Contact approximately located.

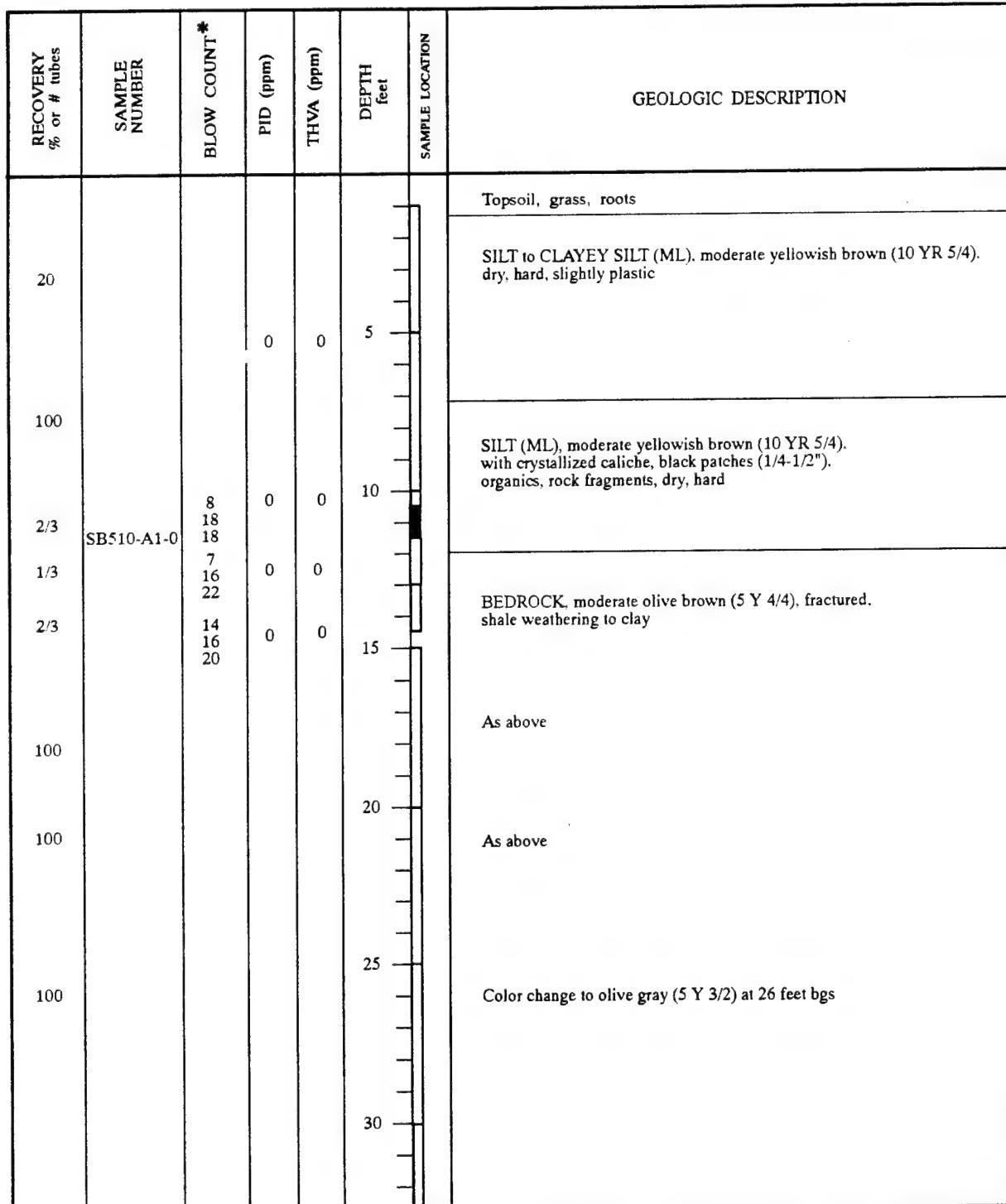
■ - Stainless-steel tube sample submitted for laboratory analysis.

NR - Not Recorded

□ - Drive or continuous core sample.

BORING NUMBER: SB510

PROJECT NUMBER:	723097	PROJECT NAME:	Travis AFB NSGS
CLIENT:	AFCEE	DRILLER:	Gregg Drilling, Inc.
LOCATION:	IRPIMS Site 22 North and South Gas Stations	DRILLING METHOD:	Hollow-stem Auger
GEOLOGIST:	H. Pietropaoli	HOLE DIAMETER:	6.5 inches
COMPLETION DATE:	6/16-17/94	TOTAL DEPTH:	35 feet below ground surface



* - Non-standard blow count; 2.5 inch OD sampler.

▽ - First encountered groundwater.

---- - Contact approximately located.

■ - Stainless-steel tube sample submitted for laboratory analysis.

NR - Not Recorded

□ - Drive or continuous core sample.

BORING NUMBER: SB510

PROJECT NUMBER:	723097	PROJECT NAME:	Travis AFB NSGS
CLIENT:	AFCEE	DRILLER:	Gregg Drilling, Inc.
LOCATION:	IRPIMS Site 22 North and South Gas Stations	DRILLING METHOD:	Hollow-stem Auger
GEOLOGIST:	H. Pietropaoli	HOLE DIAMETER:	6.5 inches
COMPLETION DATE:	6/16-17/94	TOTAL DEPTH:	35 feet below ground surface

RECOVERY % or # tubes	SAMPLE NUMBER	BLOW COUNT*	PID (ppm)	THVA (ppm)	DEPTH feet	SAMPLE LOCATION	GEOLOGIC DESCRIPTION	
							As above, with light gray rock (shale) fragments	T.D. 35.0'
100					35			

* - Non-standard blow count; 2.5 inch OD sampler.

▽ - First encountered groundwater.

---- - Contact approximately located.

█ - Stainless-steel tube sample submitted for laboratory analysis.

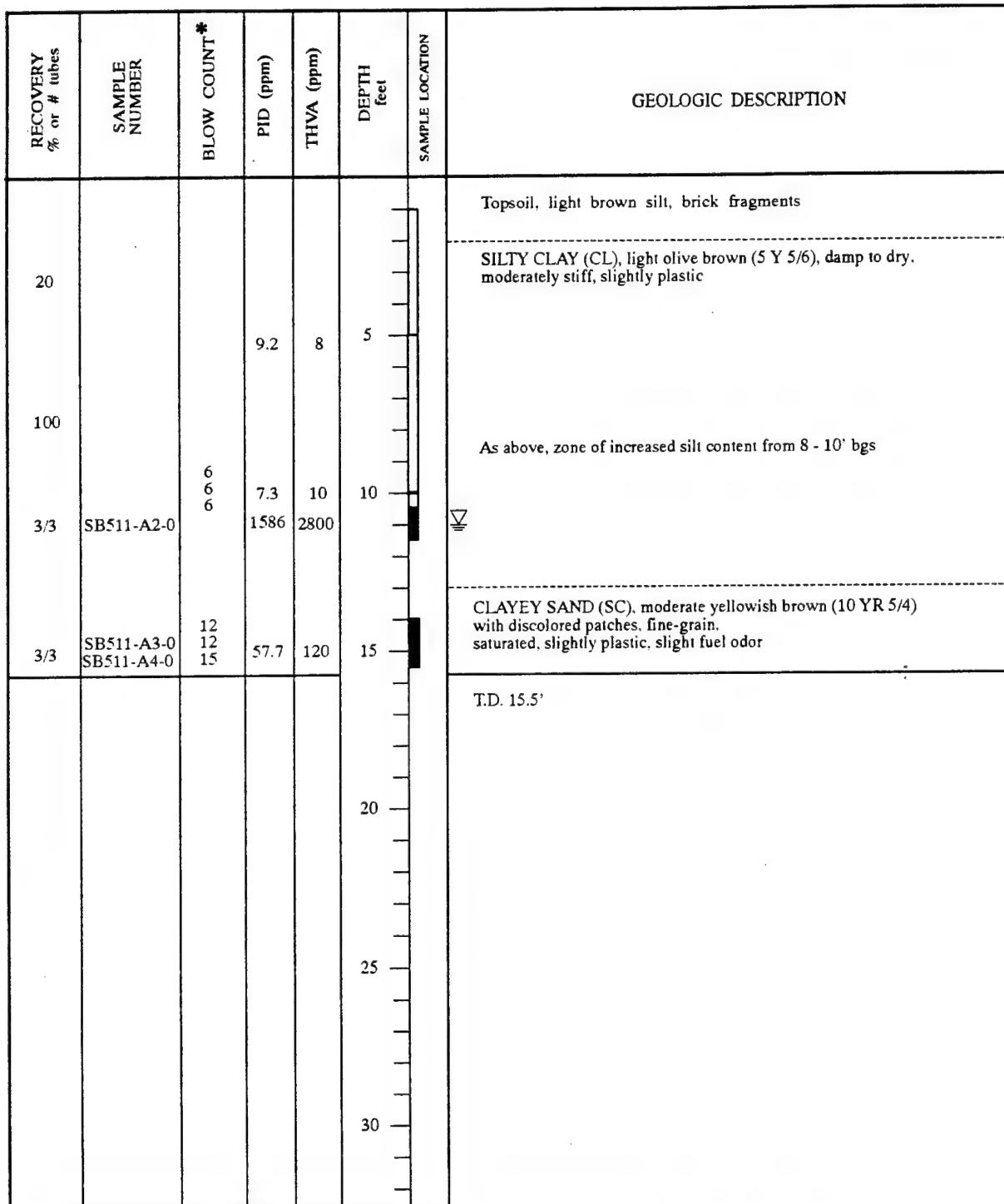
NR - Not Recorded

□ - Drive or continuous core sample.

BSG10-2

BORING NUMBER: SB511

PROJECT NUMBER:	723097	PROJECT NAME:	Travis AFB NSGS
CLIENT:	AFCEE	DRILLER:	Gregg Drilling, Inc.
LOCATION:	IRPIMS Site 22 North and South Gas Stations	DRILLING METHOD:	Hollow-stem Auger
GEOLOGIST:	H. Pietropaoli	HOLE DIAMETER:	6.5 inches
COMPLETION DATE:	6/29/94	TOTAL DEPTH:	15.5 feet below ground surface



* - Non-standard blow count: 2.5 inch OD sampler.

█ - Stainless-steel tube sample submitted for laboratory analysis.

▽ - First encountered groundwater.

---- - Contact approximately located.

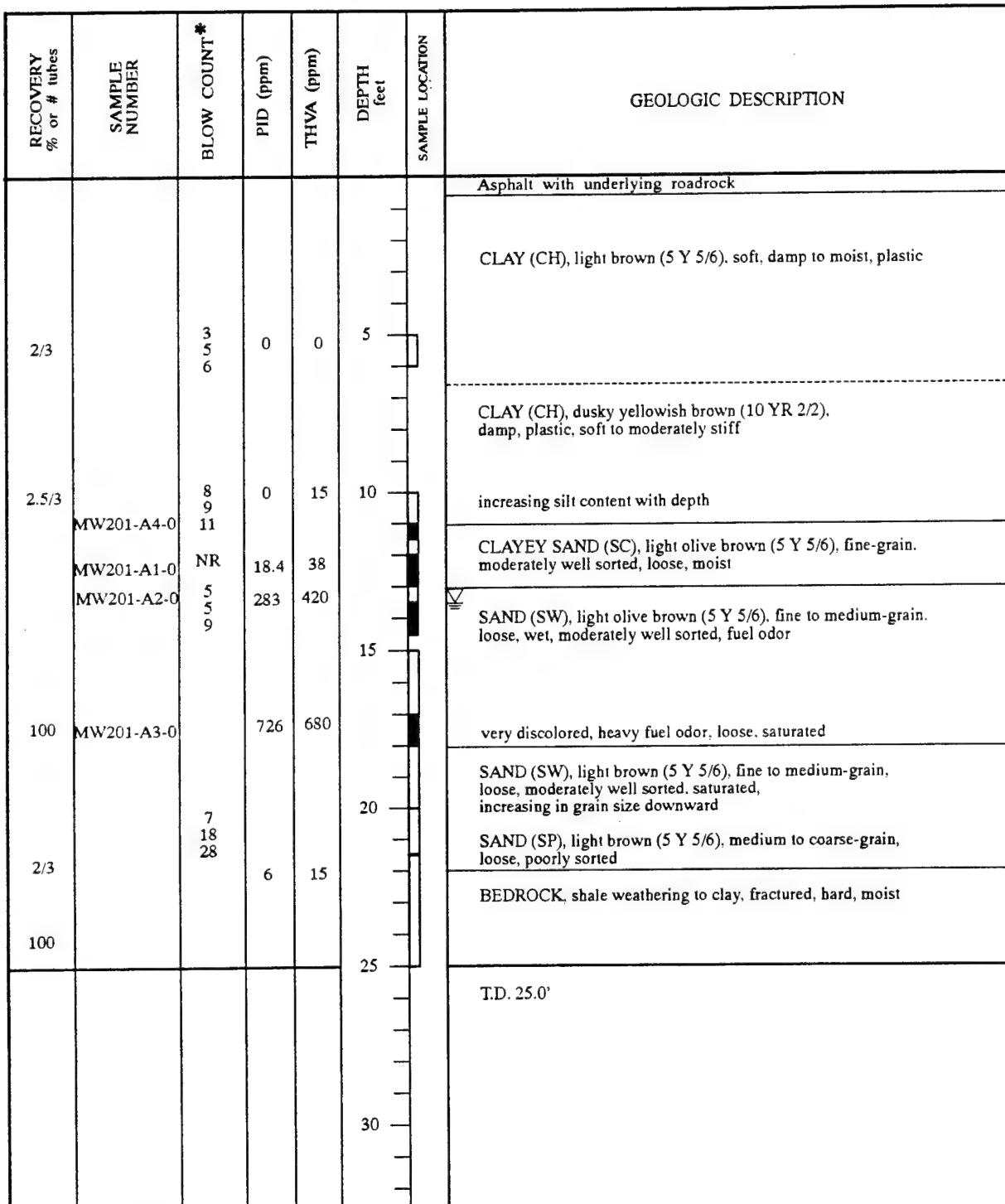
NR - Not Recorded

□ - Drive or continuous core sample.

SB511

BORING NUMBER: MW201

PROJECT NUMBER:	723097	PROJECT NAME:	Travis AFB NSGS
CLIENT:	AFCEE	DRILLER:	Gregg Drilling, Inc.
LOCATION:	IRPIMS Site 22 North and South Gas Stations	DRILLING METHOD:	Hollow-stem Auger
GEOLOGIST:	H. Pietropaoli	HOLE DIAMETER:	6.5 (enlarged to 10.5) inches
COMPLETION DATE:	6/17/94	TOTAL DEPTH:	25 feet below ground surface



* - Non-standard blow count: 2.5 inch OD sampler.

■ - Stainless-steel tube sample submitted for laboratory analysis.

▽ - First encountered groundwater.

---- - Contact approximately located.

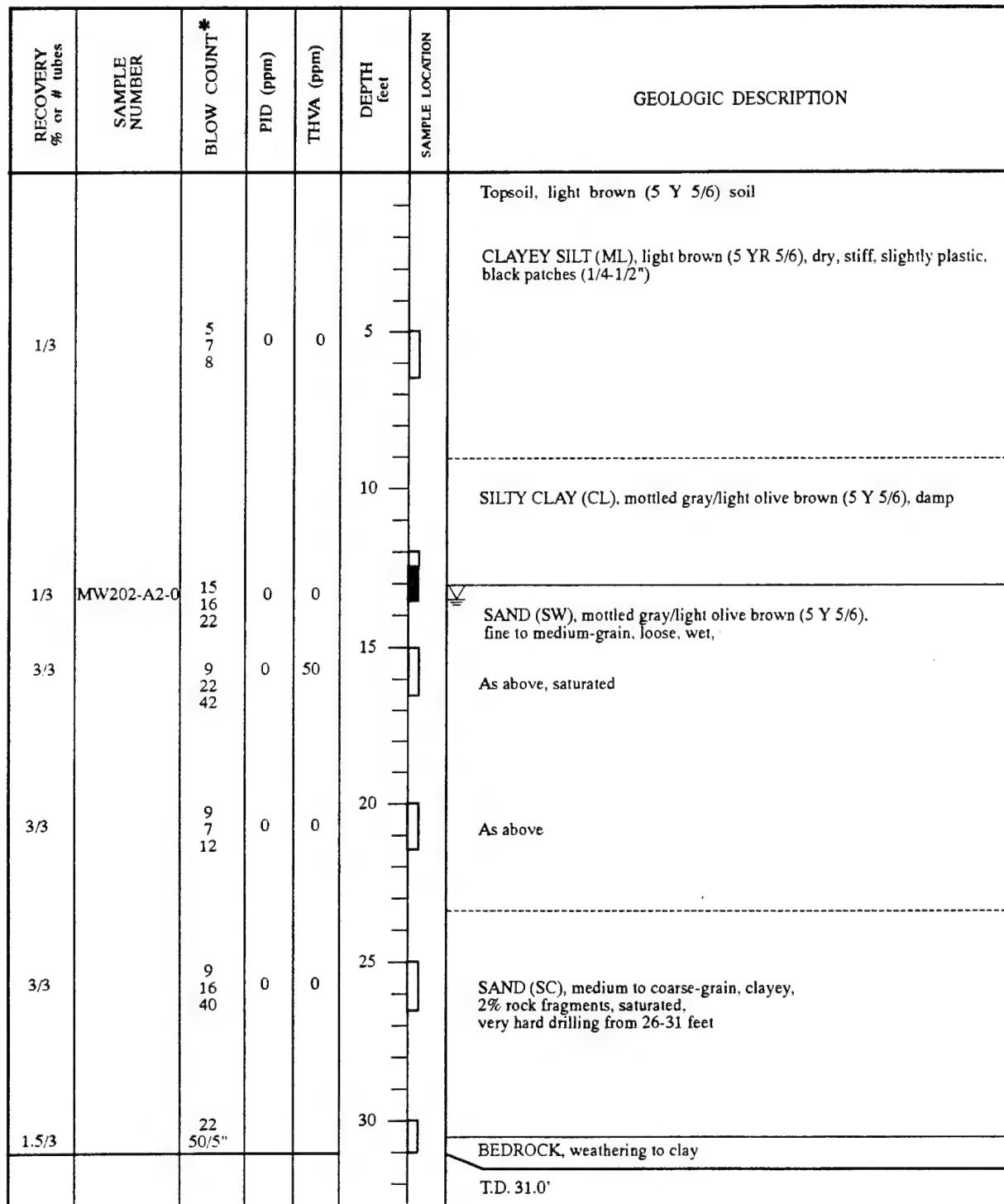
NR - Not Recorded

□ - Drive or continuous core sample.

ns-201

BORING NUMBER: MW202

PROJECT NUMBER: 723097	PROJECT NAME: Travis AFB NSGS
CLIENT: AFCEE	DRILLER: Gregg Drilling, Inc.
LOCATION: IRPIMS Site 22	DRILLING METHOD: Hollow-stem Auger
North and South Gas Stations	
GEOLOGIST: H. Pietropaoli	HOLE DIAMETER: 6.5 (enlarged to 10.5) inches
COMPLETION DATE: 6/30-7/1/94	TOTAL DEPTH: 31 feet below ground surface



* - Non-standard blow count: 2.5 inch OD sampler.

▽ - First encountered groundwater.

---- - Contact approximately located.

■ - Stainless-steel tube sample submitted for laboratory analysis.

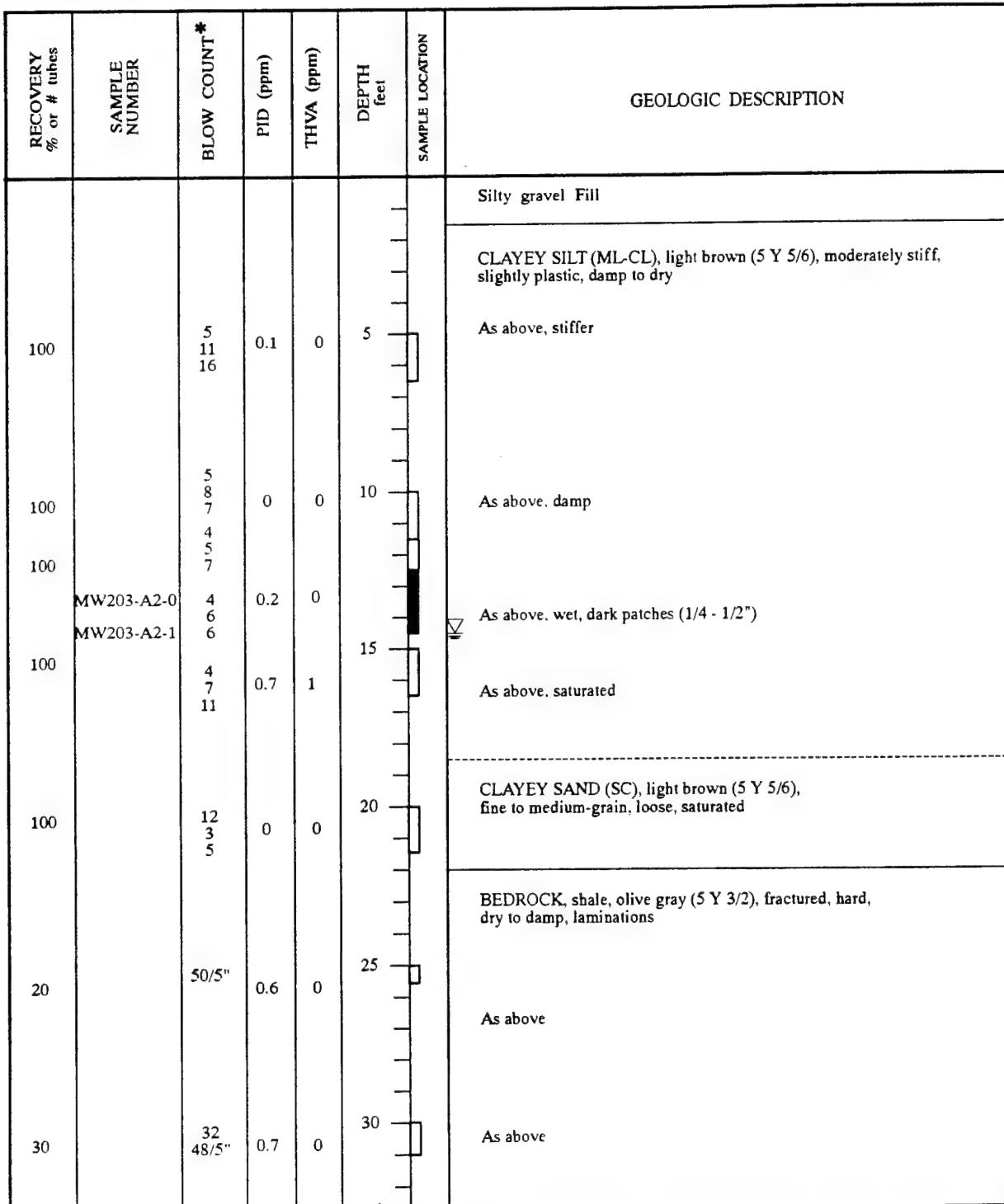
NR - Not Recorded

□ - Drive or continuous core sample.

nsg202

BORING NUMBER: MW203

PROJECT NUMBER:	723097	PROJECT NAME:	Travis AFB NSGS
CLIENT:	AFCEE	DRILLER:	Gregg Drilling, Inc.
LOCATION:	IRPIMS Site 22 North and South Gas Stations	DRILLING METHOD:	Hollow-stem Auger
GEOLOGIST:	H. Pietropaoli	HOLE DIAMETER:	6.5 (enlarged to 10.5) inches
COMPLETION DATE:	6/13/94	TOTAL DEPTH:	36.0 feet below ground surface



* - Non-standard blow count; 2.5 inch OD sampler.

■ - Stainless-steel tube sample submitted for laboratory analysis.

▽ - First encountered groundwater.

---- - Contact approximately located.

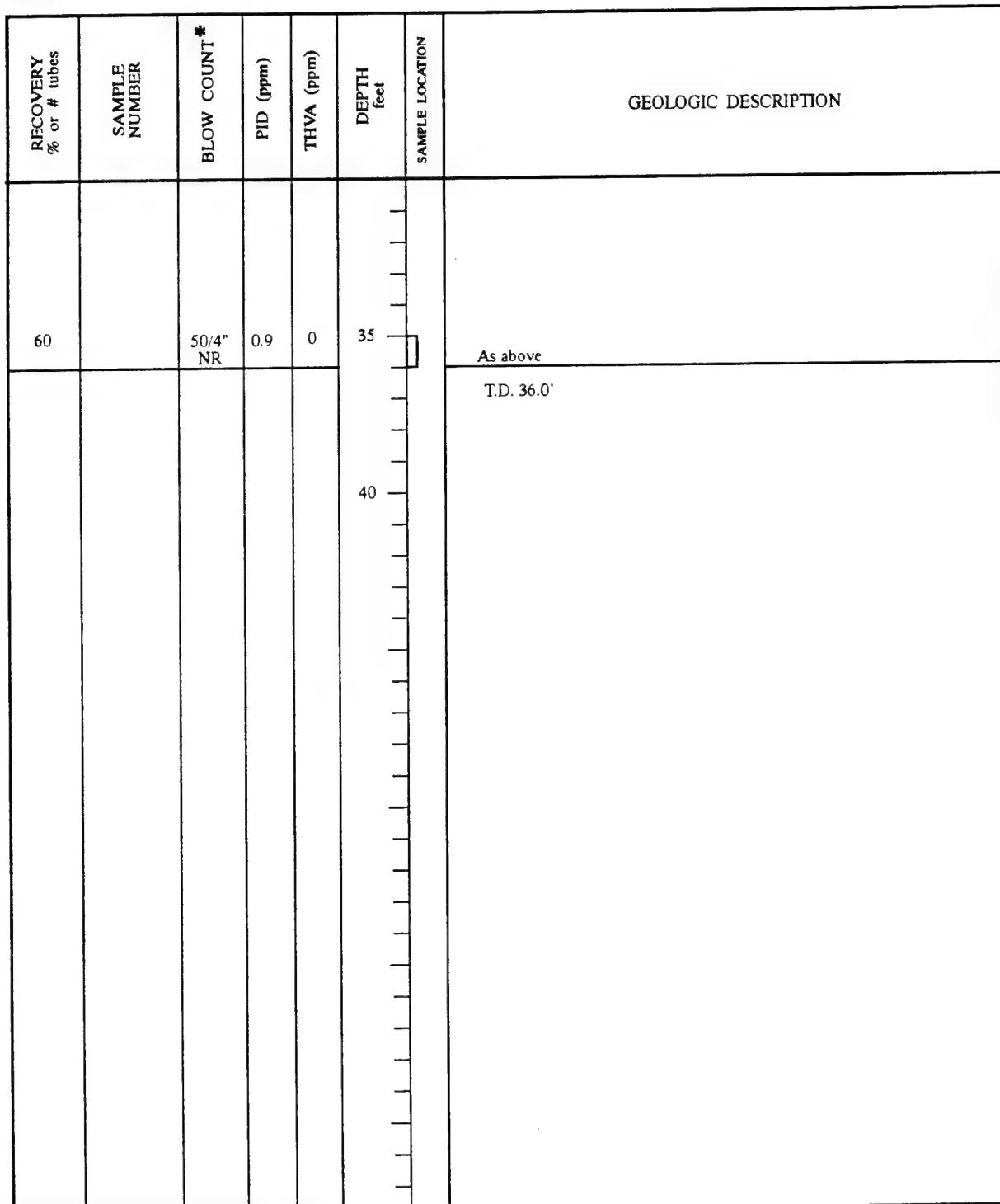
NR - Not Recorded

□ - Drive or continuous core sample.

MW203

BORING NUMBER: MW203

PROJECT NUMBER:	723097	PROJECT NAME:	Travis AFB NSGS
CLIENT:	AFCEE	DRILLER:	Gregg Drilling, Inc.
LOCATION:	IRPIMS Site 22 North and South Gas Stations	DRILLING METHOD:	Hollow-stem Auger
GEOLOGIST:	H. Pietropoli	HOLE DIAMETER:	6.5 (enlarged to 10.5) inches
COMPLETION DATE:	6/13/94	TOTAL DEPTH:	36.0 feet below ground surface



* - Non-standard blow count: 2.5 inch OD sampler.

▽ - First encountered groundwater.

---- - Contact approximately located.

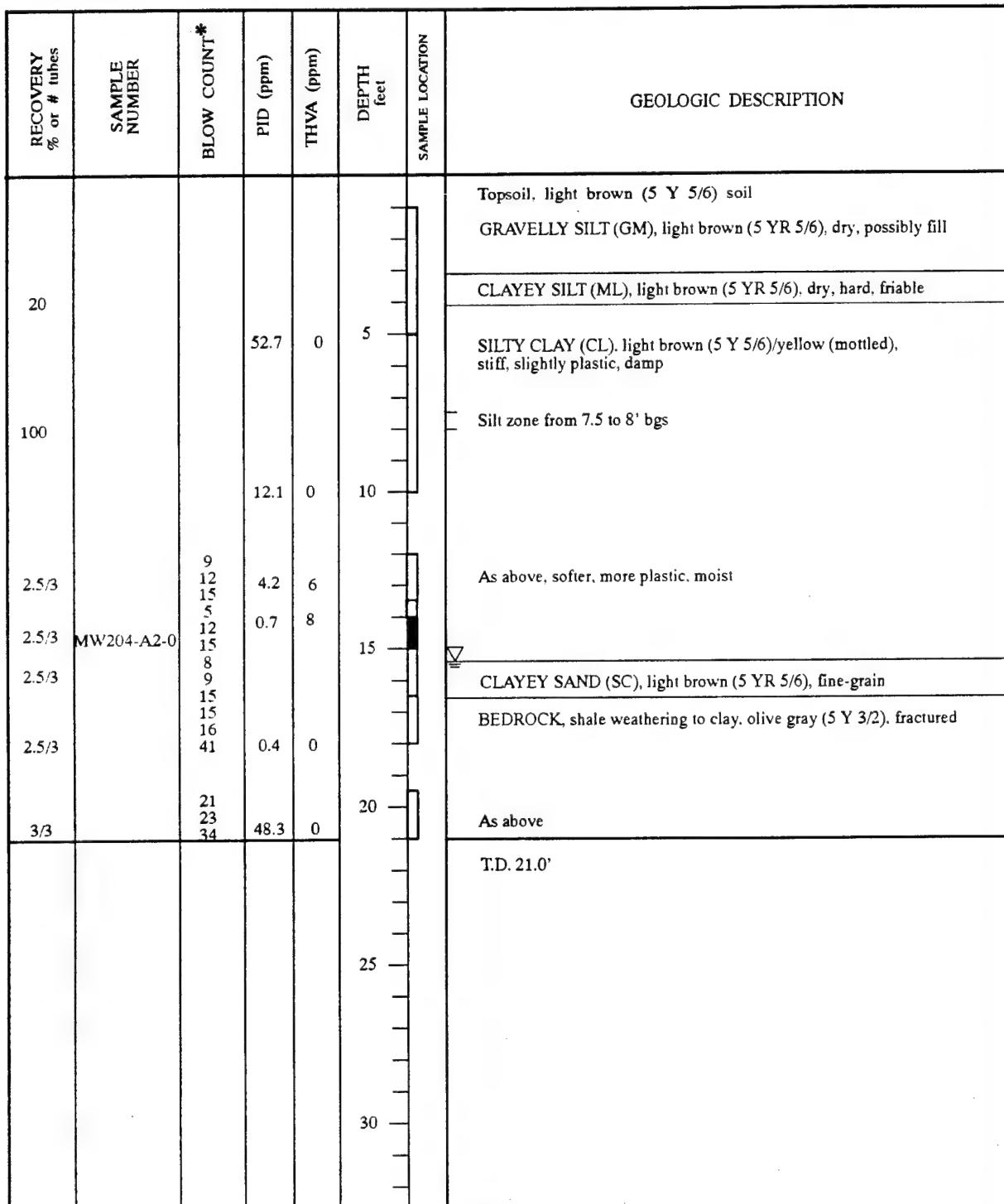
■ - Stainless-steel tube sample submitted for laboratory analysis.

NR - Not Recorded

□ - Drive or continuous core sample.

BORING NUMBER: MW204

PROJECT NUMBER:	723097	PROJECT NAME:	Travis AFB NSGS
CLIENT:	AFCEE	DRILLER:	Gregg Drilling, Inc.
LOCATION:	IRPIMS Site 22 North and South Gas Stations	DRILLING METHOD:	Hollow-stem Auger
GEOLOGIST:	H. Pietropaoli	HOLE DIAMETER:	6.5 (enlarged to 10.5) inches
COMPLETION DATE:	6/29/94	TOTAL DEPTH:	21 feet below ground surface



* - Non-standard blow count: 2.5 inch OD sampler.

▽ - First encountered groundwater.

---- - Contact approximately located.

■ - Stainless-steel tube sample submitted for laboratory analysis.

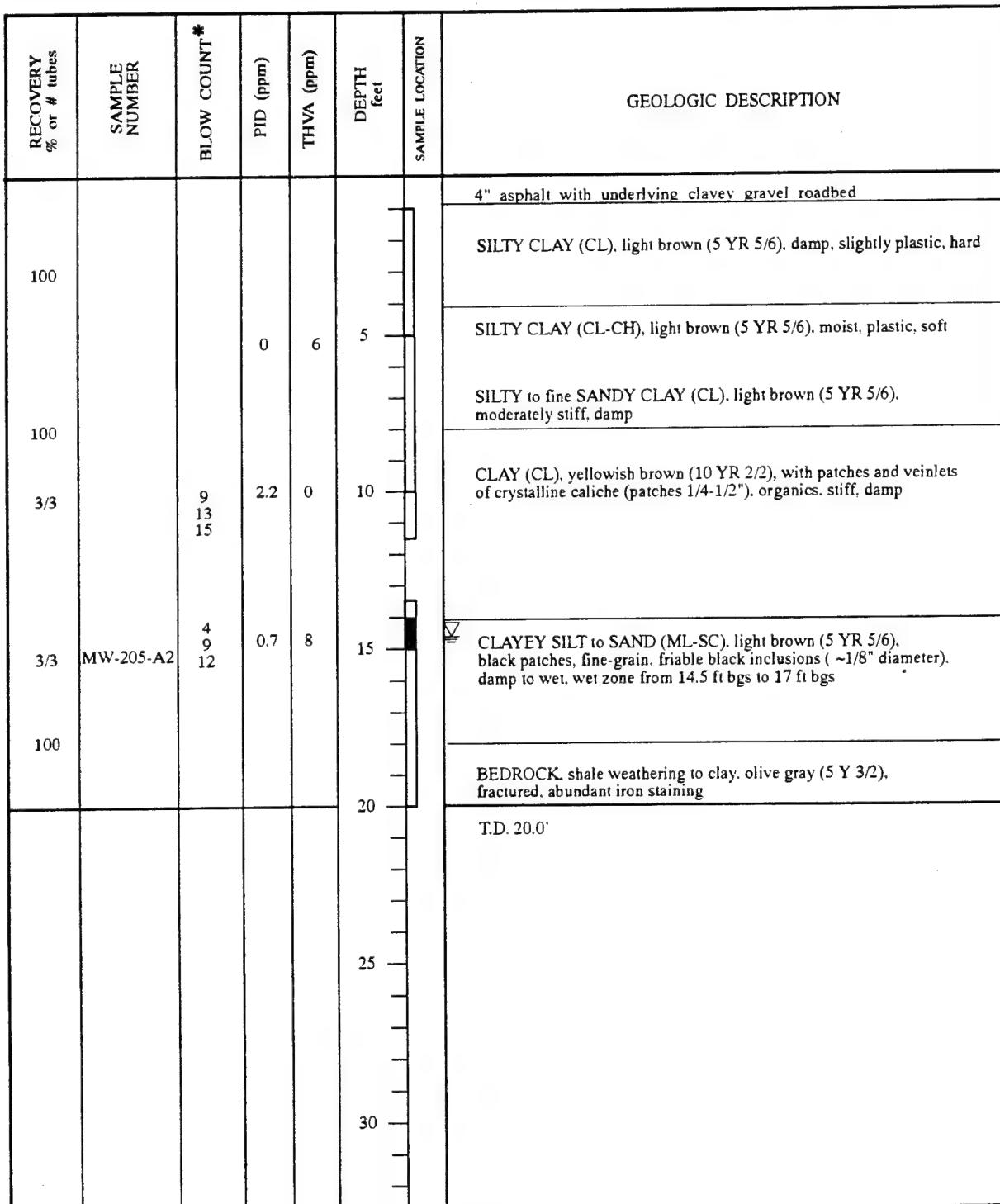
NR - Not Recorded

□ - Drive or continuous core sample.

ns204

BORING NUMBER: MW205

PROJECT NUMBER:	723097	PROJECT NAME:	Travis AFB NSGS
CLIENT:	AFCEE	DRILLER:	Gregg Drilling, Inc.
LOCATION:	IRPIMS Site 22 North and South Gas Stations	DRILLING METHOD:	Hollow-stem Auger
GEOLOGIST:	H. Pietropaoli	HOLE DIAMETER:	6.5 (enlarged to 10.5) inches
COMPLETION DATE:	6/15/94	TOTAL DEPTH:	20 feet below ground surface



* - Non-standard blow count; 2.5 inch OD sampler.

▽ - First encountered groundwater.

---- - Contact approximately located.

█ - Stainless-steel tube sample submitted for laboratory analysis.

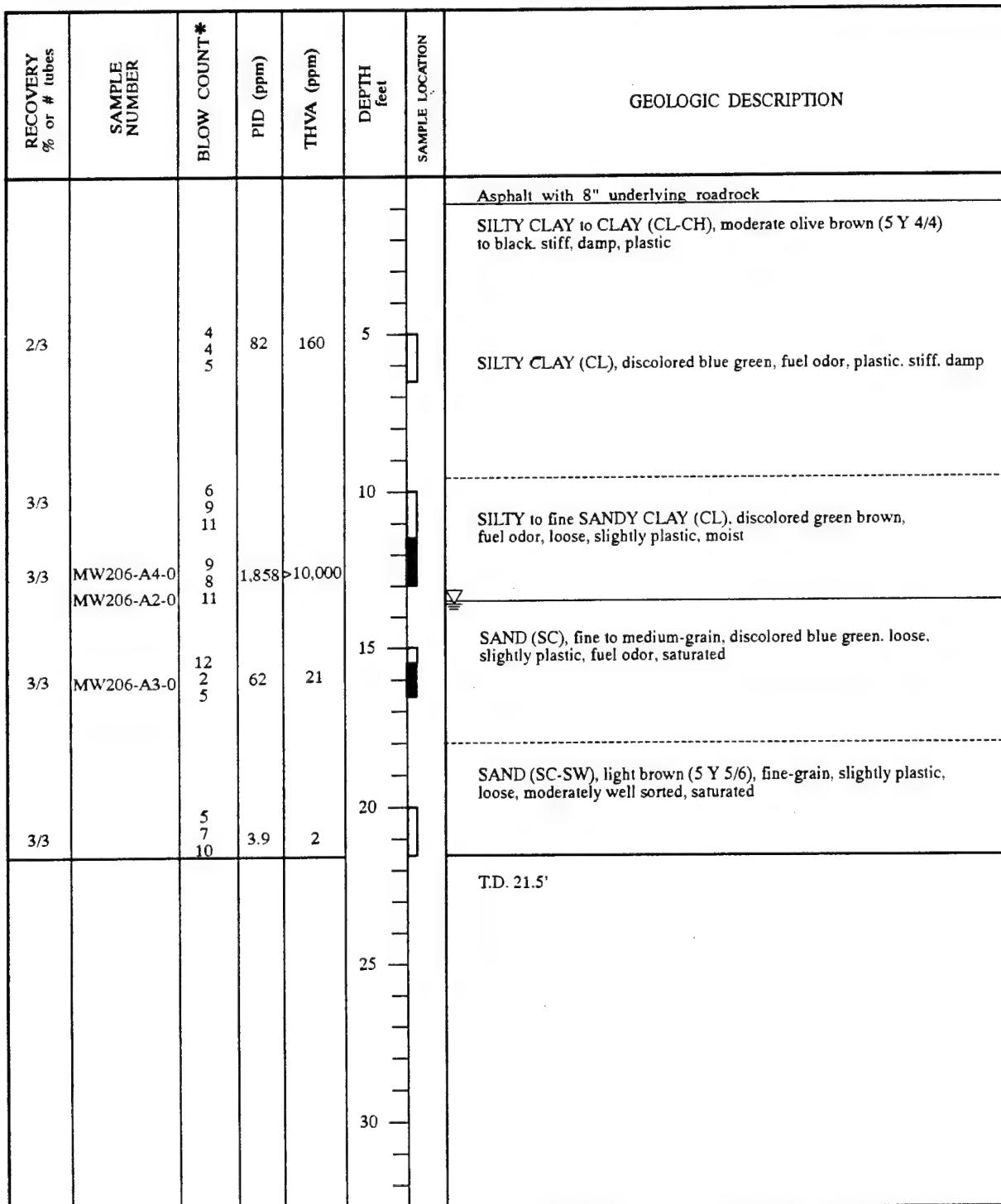
NR - Not Recorded

□ - Drive or continuous core sample.

BGS205

BORING NUMBER: MW206

PROJECT NUMBER:	723097	PROJECT NAME:	Travis AFB NSGS
CLIENT:	AFCEE	DRILLER:	Gregg Drilling, Inc.
LOCATION:	IRPIMS Site 22 North and South Gas Stations	DRILLING METHOD:	Hollow-stem Auger
GEOLOGIST:	H. Pietropaoli	HOLE DIAMETER:	6.5 (enlarged to 10.5) inches
COMPLETION DATE:	6/14/94	TOTAL DEPTH:	21.5 feet below ground surface



* - Non-standard blow count; 2.5 inch OD sampler.

- Stainless-steel tube sample submitted for laboratory analysis.

▽ - First encountered groundwater.

NR - Not Recorded

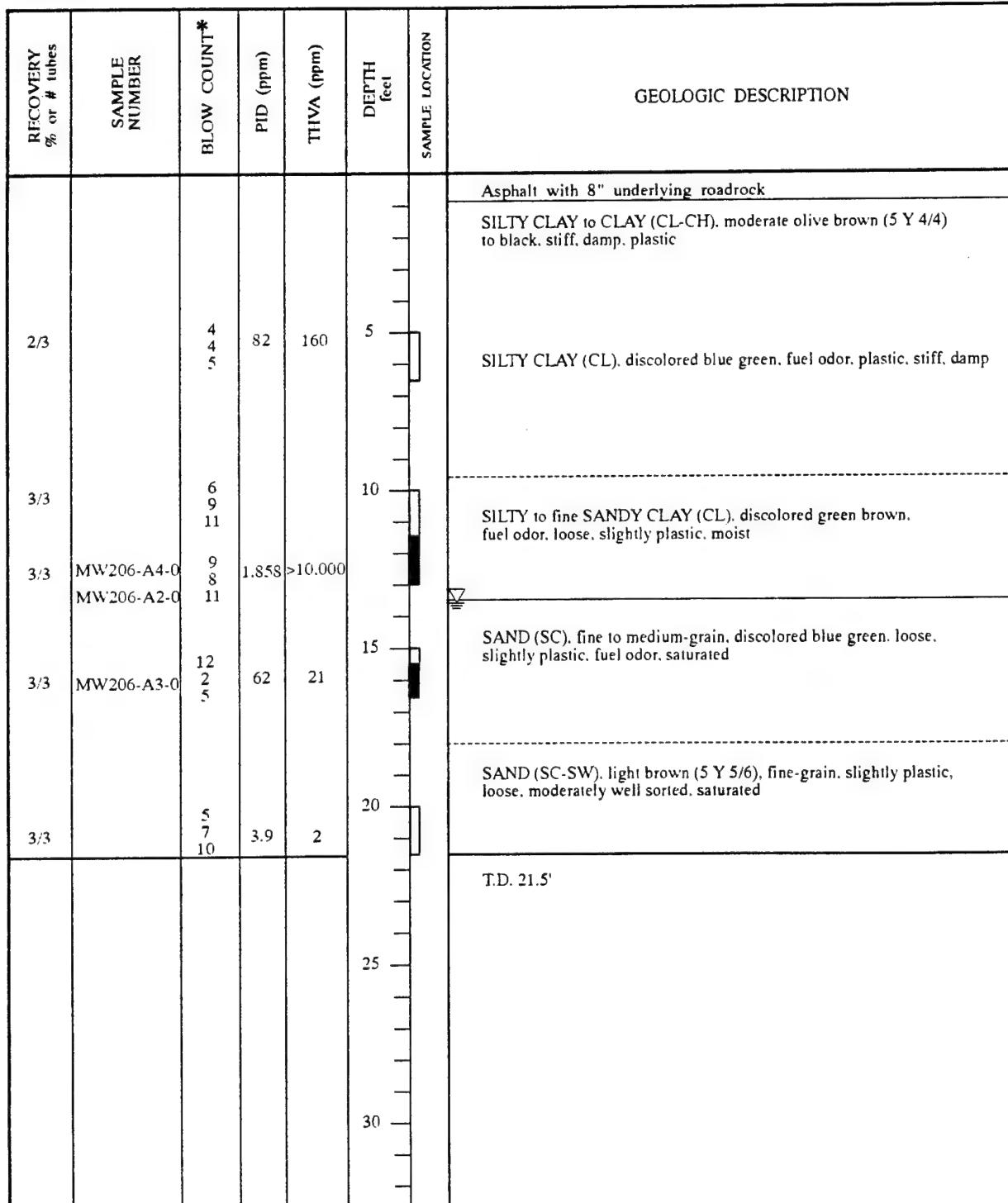
---- - Contact approximately located.

□ - Drive or continuous core sample.

nsg206

BORING NUMBER: MW206

PROJECT NUMBER:	723097	PROJECT NAME:	Travis AFB NSGS
CLIENT:	AFCEE	DRILLER:	Gregg Drilling, Inc.
LOCATION:	IRPIMS Site 22 North and South Gas Stations	DRILLING METHOD:	Hollow-stem Auger
GEOLOGIST:	H. Pietropaoli	HOLE DIAMETER:	6.5 (enlarged to 10.5) inches
COMPLETION DATE:	6/14/94	TOTAL DEPTH:	21.5 feet below ground surface

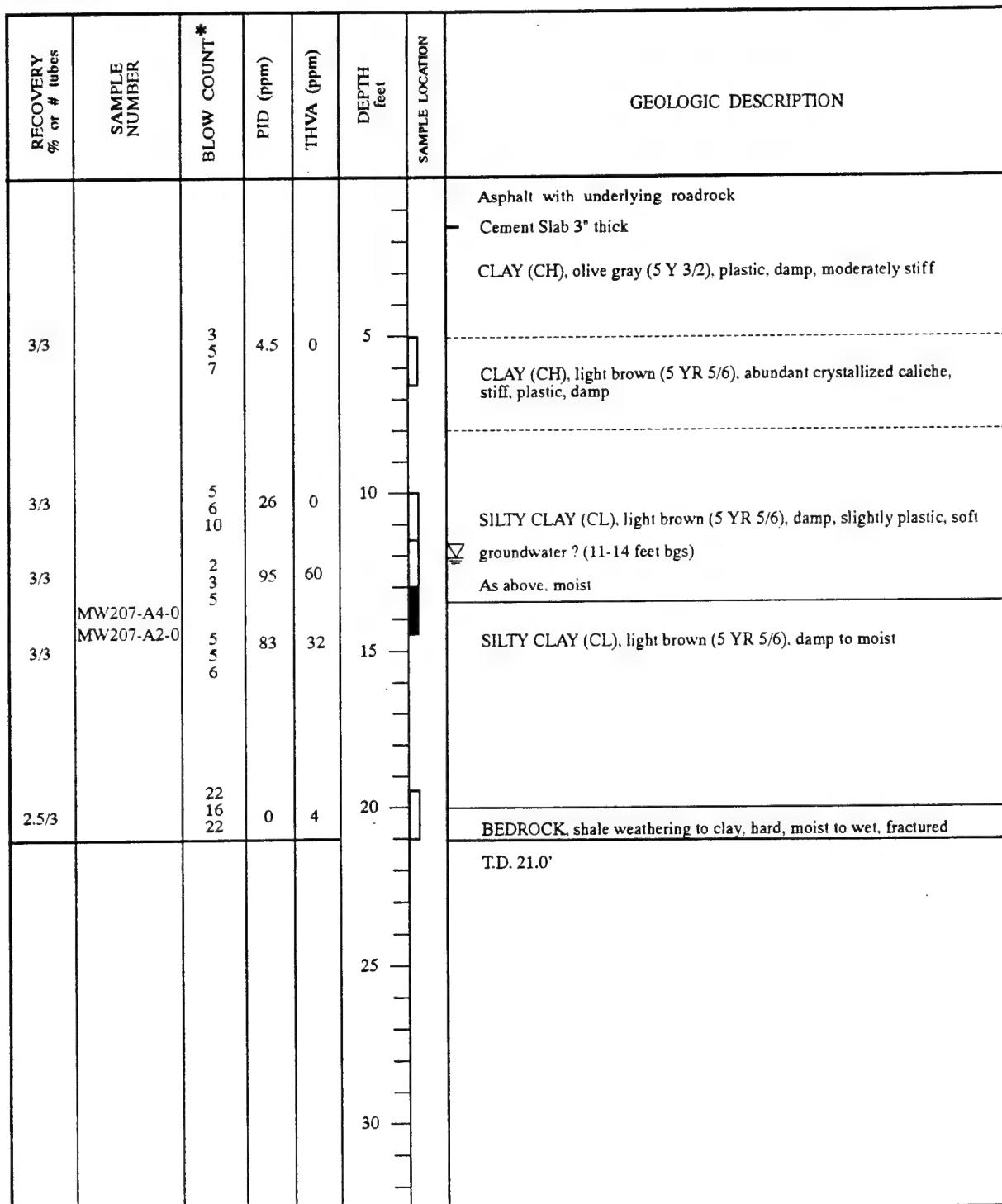


* - Non-standard blow count: 2.5 inch OD sampler.
 - First encountered groundwater.
 - Contact approximately located.

 - Stainless-steel tube sample submitted for laboratory analysis.
 NR - Not Recorded  - Drive or continuous core sample.

BORING NUMBER: MW207

PROJECT NUMBER:	723097	PROJECT NAME:	Travis AFB NSGS
CLIENT:	AFCEE	DRILLER:	Gregg Drilling, Inc.
LOCATION:	IRPIMS Site 22 North and South Gas Stations	DRILLING METHOD:	Hollow-stem Auger
GEOLOGIST:	H. Pietropaoli	HOLE DIAMETER:	6.5 (enlarged to 10.5) inches
COMPLETION DATE:	6/15-16/94	TOTAL DEPTH:	21 feet below ground surface



* - Non-standard blow count; 2.5 inch OD sampler.

▽ - First encountered groundwater.

---- - Contact approximately located.

■ - Stainless-steel tube sample submitted for laboratory analysis.

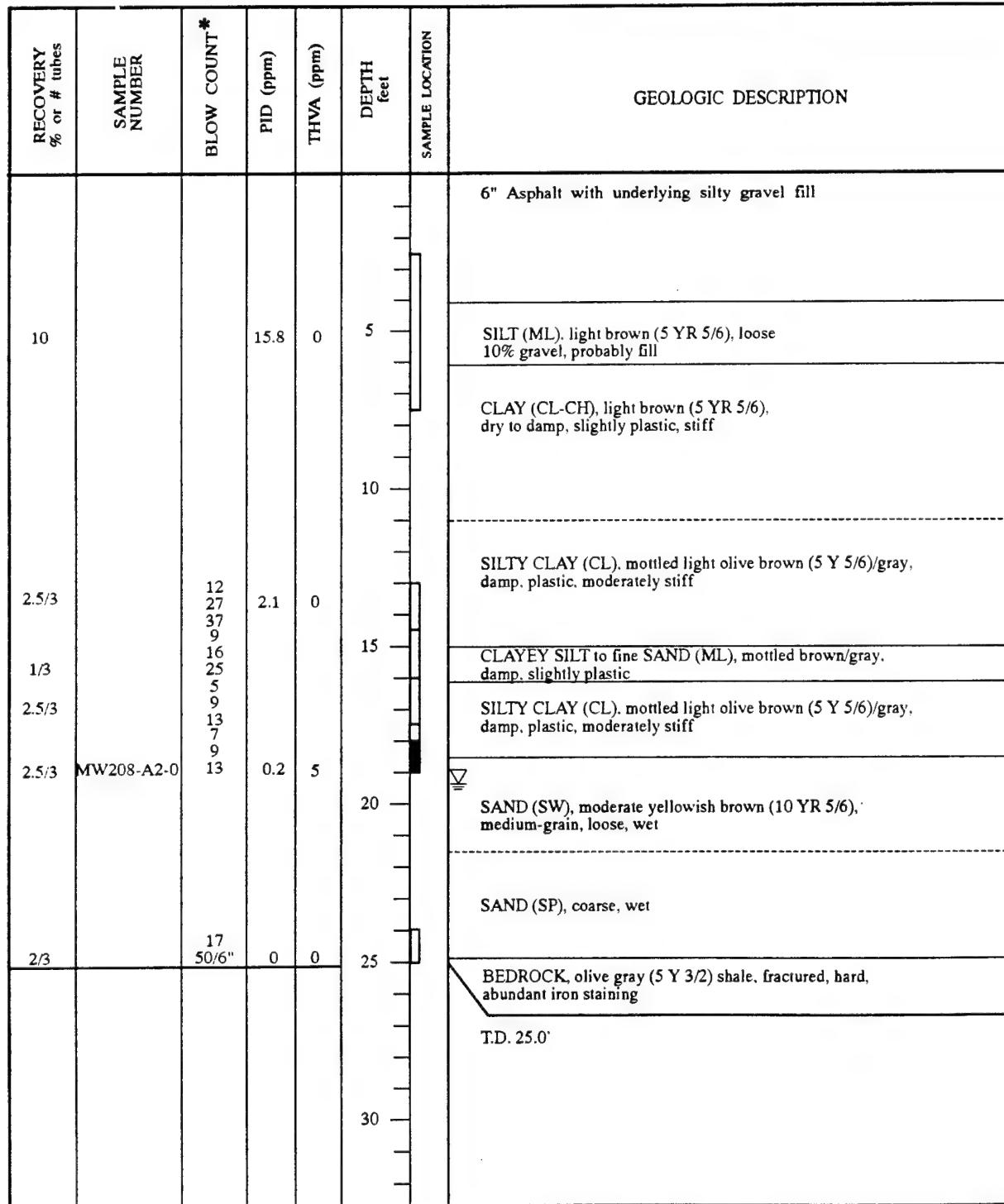
NR - Not Recorded

□ - Drive or continuous core sample.

Dsg207

BORING NUMBER: MW208

PROJECT NUMBER:	723097	PROJECT NAME:	Travis AFB NSGS
CLIENT:	AFCEE	DRILLER:	Gregg Drilling, Inc.
LOCATION:	IRPIMS Site 22 North and South Gas Stations	DRILLING METHOD:	Hollow-stem Auger
GEOLOGIST:	H. Pietropaoli	HOLE DIAMETER:	6.5 (enlarged to 10.5) inches
COMPLETION DATE:	6/30/94	TOTAL DEPTH:	25.0 feet below ground surface



* - Non-standard blow count; 2.5 inch OD sampler.

▽ - First encountered groundwater.

---- - Contact approximately located.

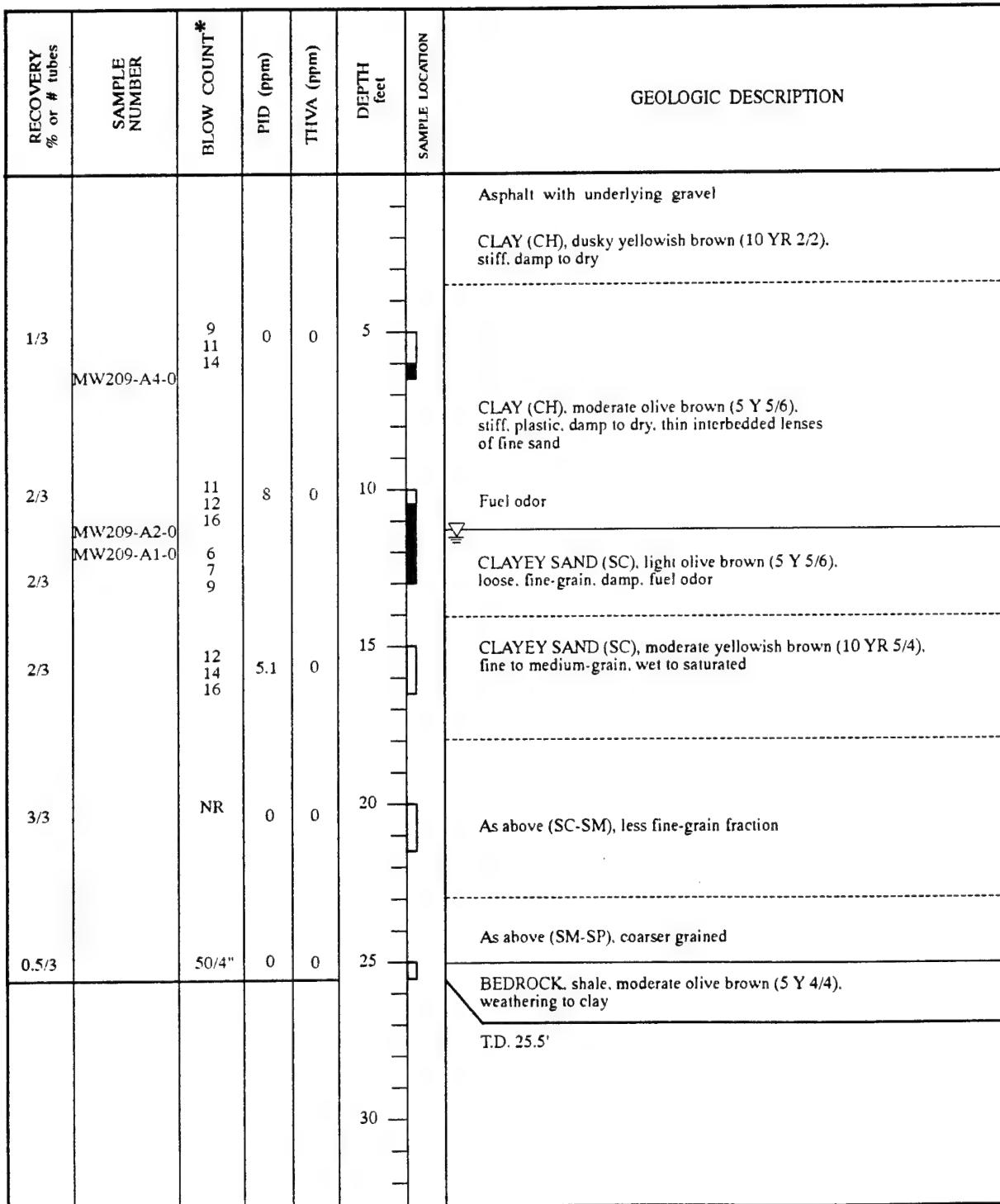
■ - Stainless-steel tube sample submitted for laboratory analysis.

NR - Not Recorded

□ - Drive or continuous core sample.

BORING NUMBER: MW209

PROJECT NUMBER:	723097	PROJECT NAME:	Travis AFB NSGS
CLIENT:	AFCEE	DRILLER:	Gregg Drilling, Inc.
LOCATION:	IRPIMS Site 22 North and South Gas Stations	DRILLING METHOD:	Hollow-stem Auger
GEOLOGIST:	H. Pietropaoli	HOLE DIAMETER:	6.5 (enlarged to 10.5) inches
COMPLETION DATE:	6/20/94	TOTAL DEPTH:	25.5 feet below ground surface



* - Non-standard blow count: 2.5 inch OD sampler.

▽ - First encountered groundwater.

- Contact approximately located.

- Stainless-steel tube sample submitted for laboratory analysis

NR - Not Recorded

- Drive or continuous core sample.

BORING NUMBER: MW210

PROJECT NUMBER:	723097	PROJECT NAME:	Travis AFB NSGS
CLIENT:	AFCEE	DRILLER:	Gregg Drilling, Inc.
LOCATION:	IRPIMS Site 22	DRILLING METHOD:	Hollow-stem Auger
	North and South Gas Stations		
GEOLOGIST:	H. Pietropaoli	HOLE DIAMETER:	6.5 (enlarged to 10.5) inches
COMPLETION DATE:	6/29-30/94	TOTAL DEPTH:	24 feet below ground surface

RECOVERY % or # tubes	SAMPLE NUMBER	BLOW COUNT*	PID (ppm)	THVA (ppm)	DEPTH feet	SAMPLE LOCATION	GEOLOGIC DESCRIPTION	
							6"	Asphalt with underlying roadrock
50					5			
100								
2/3	MW210-A2-0	6	126	120	10			CLAY (CH), dusky yellowish brown (10 YR 2/2), plastic, moderately stiff, dry to damp
2/3	MW210-A3-0	7 9 4 4 8	5.2	12	10			CLAYEY SAND (SC). discolored green, loose, moist, fine-grain, fuel odor
					15			Oily zone, saturated, color change
100					15			CLAYEY SAND (SC), light brown (5 YR 5/6). saturated, loose, fine-grain
100					20			As above
60					20			Fuel odor
					25			As above, coarse sand (SP) at base; 23-23.5 ft bgs. loose
					25			BEDROCK, shale, olive gray (5 Y 3/2), weathering to clay, wet
					30			T.D. 24.0'

* - Non-standard blow count; 2.5 inch OD sampler.

- Stainless-steel tube sample submitted for laboratory analysis.

▽ - First encountered groundwater.

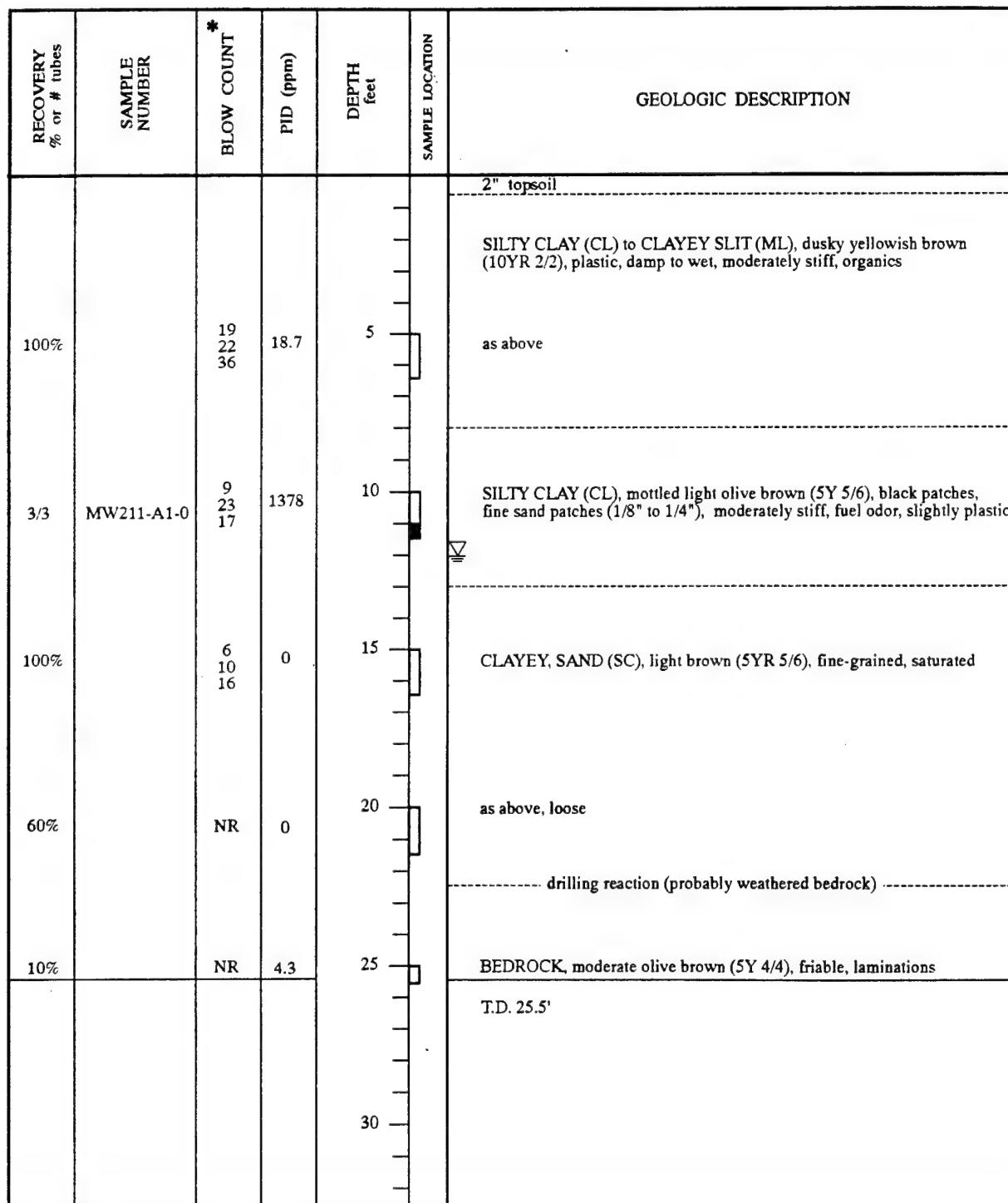
---- - Contact approximately located.

NR - Not Recorded

□ - Drive or continuous core sample.

BORING NUMBER: MW211

PROJECT NUMBER: 723097	PROJECT NAME: Travis AFB NSGS
CLIENT: AFCEE	DRILLER: Gregg Drilling, Inc.
LOCATION: IRPIMS Site 22	DRILLING METHOD: Hollow-stem Auger
North and South Gas Stations	
GEOLOGIST: H. Pietropaoli	HOLE DIAMETER: 6.5 (enlarged to 10.5) inches
COMPLETION DATE: 12/19/94	TOTAL DEPTH: 23.0 feet below ground surface



* - Non-standard blow count; 2.5 inch OD sampler.

▽ - First encountered groundwater.

- First encountered groundwater
- Contact approximately located

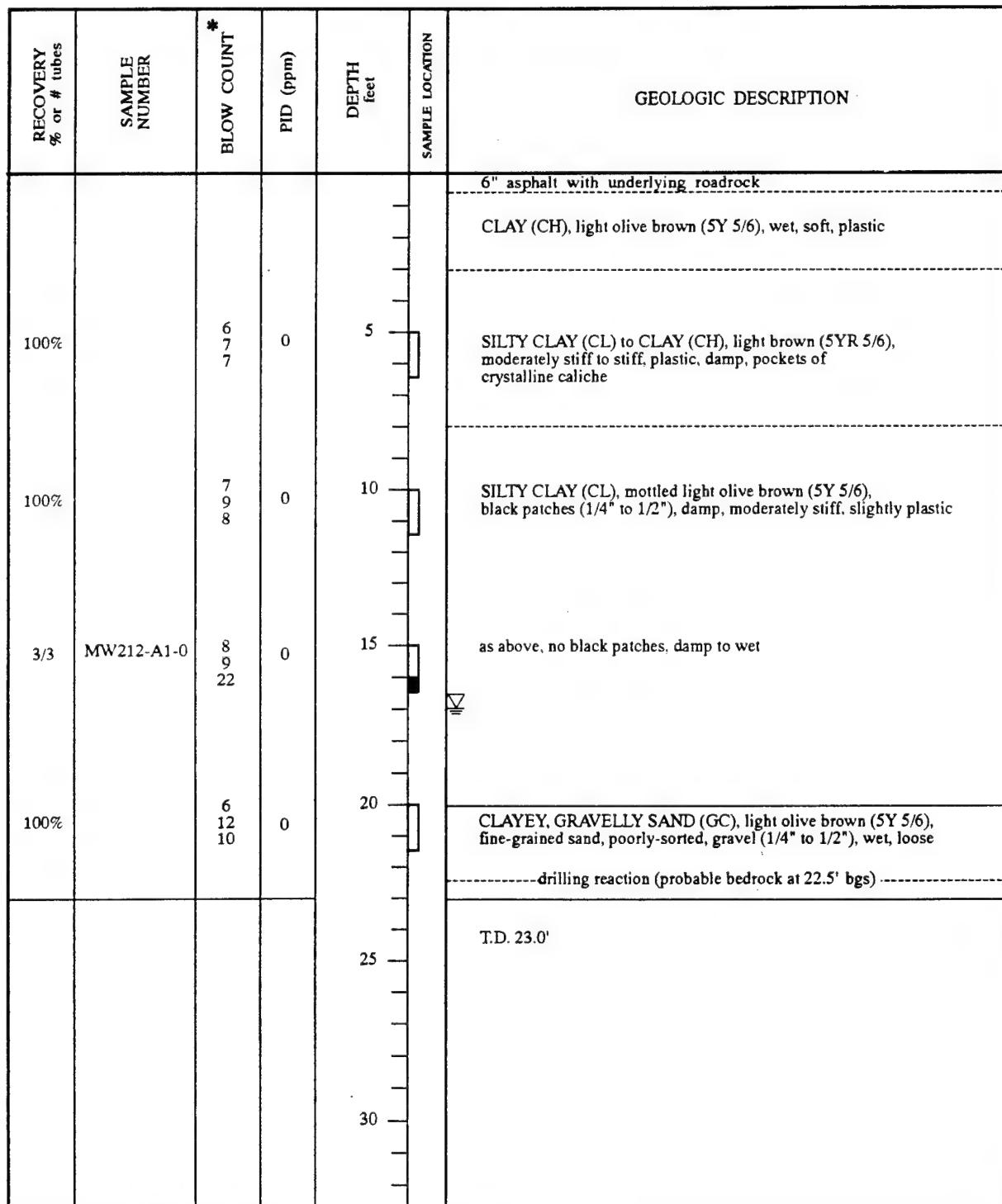
- Stainless-steel tube sample submitted for laboratory analysis.

NR - Not Recorded

- Drive or continuous core sample.

BORING NUMBER: MW212

PROJECT NUMBER:	723097	PROJECT NAME:	Travis AFB NSGS
CLIENT:	AFCEE	DRILLER:	Gregg Drilling, Inc.
LOCATION:	IRPIMS Site 22 North and South Gas Stations	DRILLING METHOD:	Hollow-stem Auger
GEOLOGIST:	H. Pietropaoli	HOLE DIAMETER:	6.5 (enlarged to 10.5) inches
COMPLETION DATE:	12/20/94	TOTAL DEPTH:	23.0 feet below ground surface

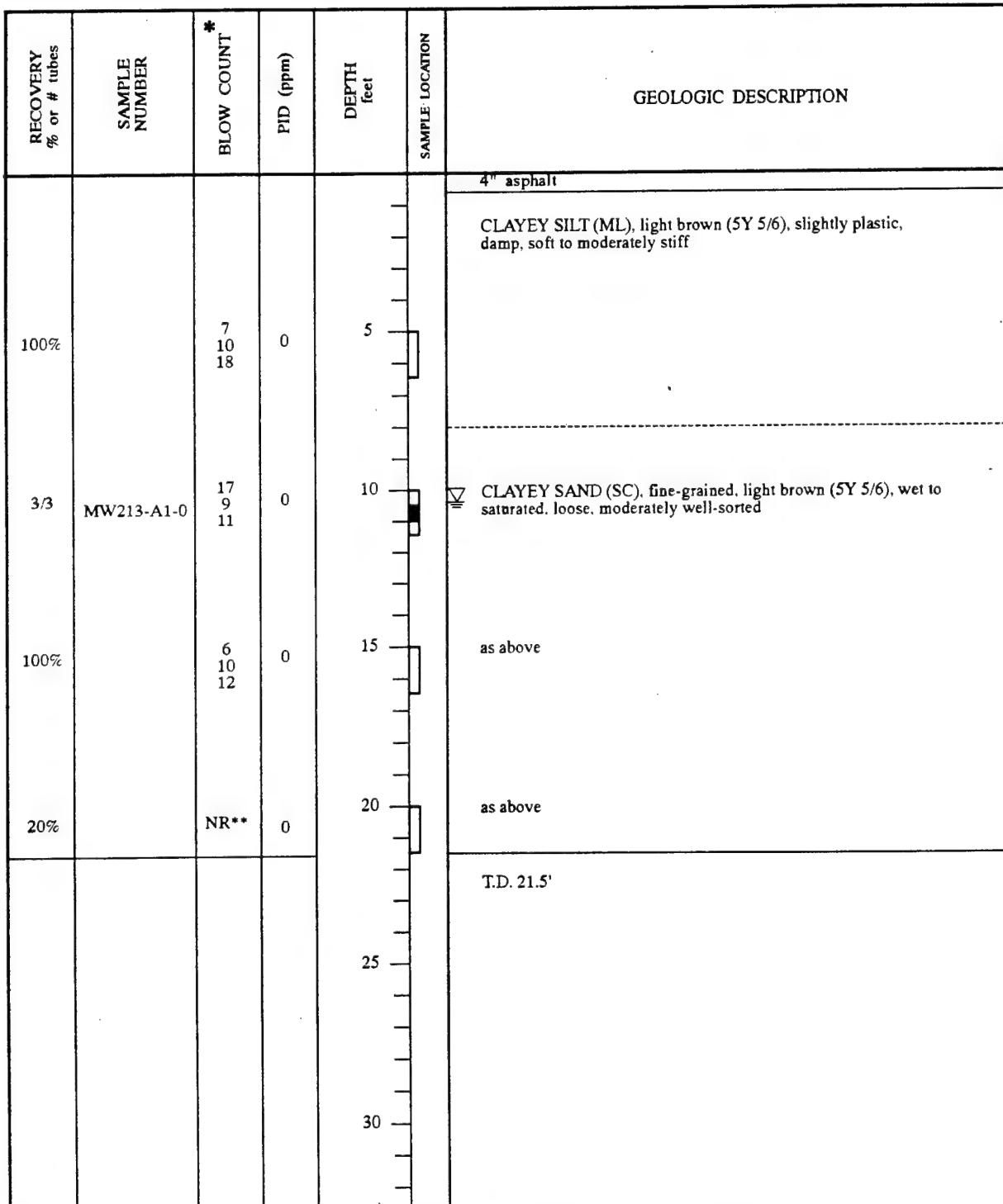


* - Non-standard blow count: 2.5 inch OD sampler.
 ▽ - First encountered groundwater.
 --- - Contact approximately located.

■ - Stainless-steel tube sample submitted for laboratory analysis.
 NR - Not Recorded
 □ - Drive or continuous core sample.

BORING NUMBER: MW213

PROJECT NUMBER:	723097	PROJECT NAME:	Travis AFB NSGS
CLIENT:	AFCEE	DRILLER:	Gregg Drilling, Inc.
LOCATION:	IRPIMS Site 22 North and South Gas Stations	DRILLING METHOD:	Hollow-stem Auger
GEOLOGIST:	H. Pietropaoli	HOLE DIAMETER:	6.5 (enlarged to 10.5) inches
COMPLETION DATE:	12/20/94	TOTAL DEPTH:	21.5 feet below ground surface

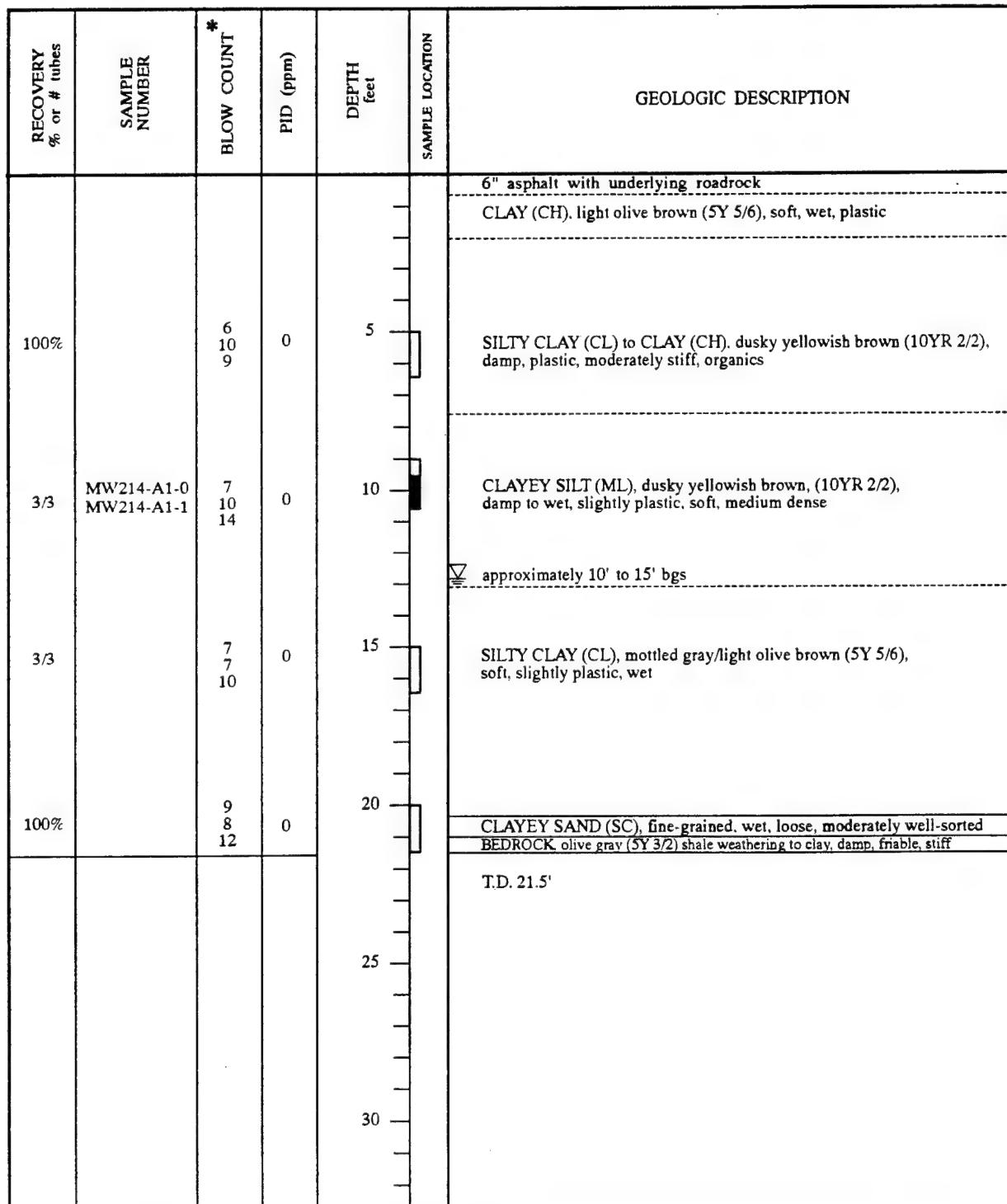


* - Non-standard blow count: 2.5 inch OD sampler.
 ▽ - First encountered groundwater.
 ---- - Contact approximately located.

** - Hammer blow not accurate below water level
 ■ - Stainless-steel tube sample submitted for laboratory analysis.
 NR - Not Recorded □ - Drive or continuous core sample.

BORING NUMBER: MW214

PROJECT NUMBER:	723097	PROJECT NAME:	Travis AFB NSGS
CLIENT:	AFCEE	DRILLER:	Gregg Drilling, Inc.
LOCATION:	IRPIMS Site 22 North and South Gas Stations	DRILLING METHOD:	Hollow-stem Auger
GEOLOGIST:	H. Pietropaoli	HOLE DIAMETER:	6.5 (enlarged to 10.5) inches
COMPLETION DATE:	12/20/94	TOTAL DEPTH:	21.5 feet below ground surface



* - Non-standard blow count: 2.5 inch OD sampler.

▽ - First encountered groundwater.

---- - Contact approximately located.

█ - Stainless-steel tube sample submitted for laboratory analysis.

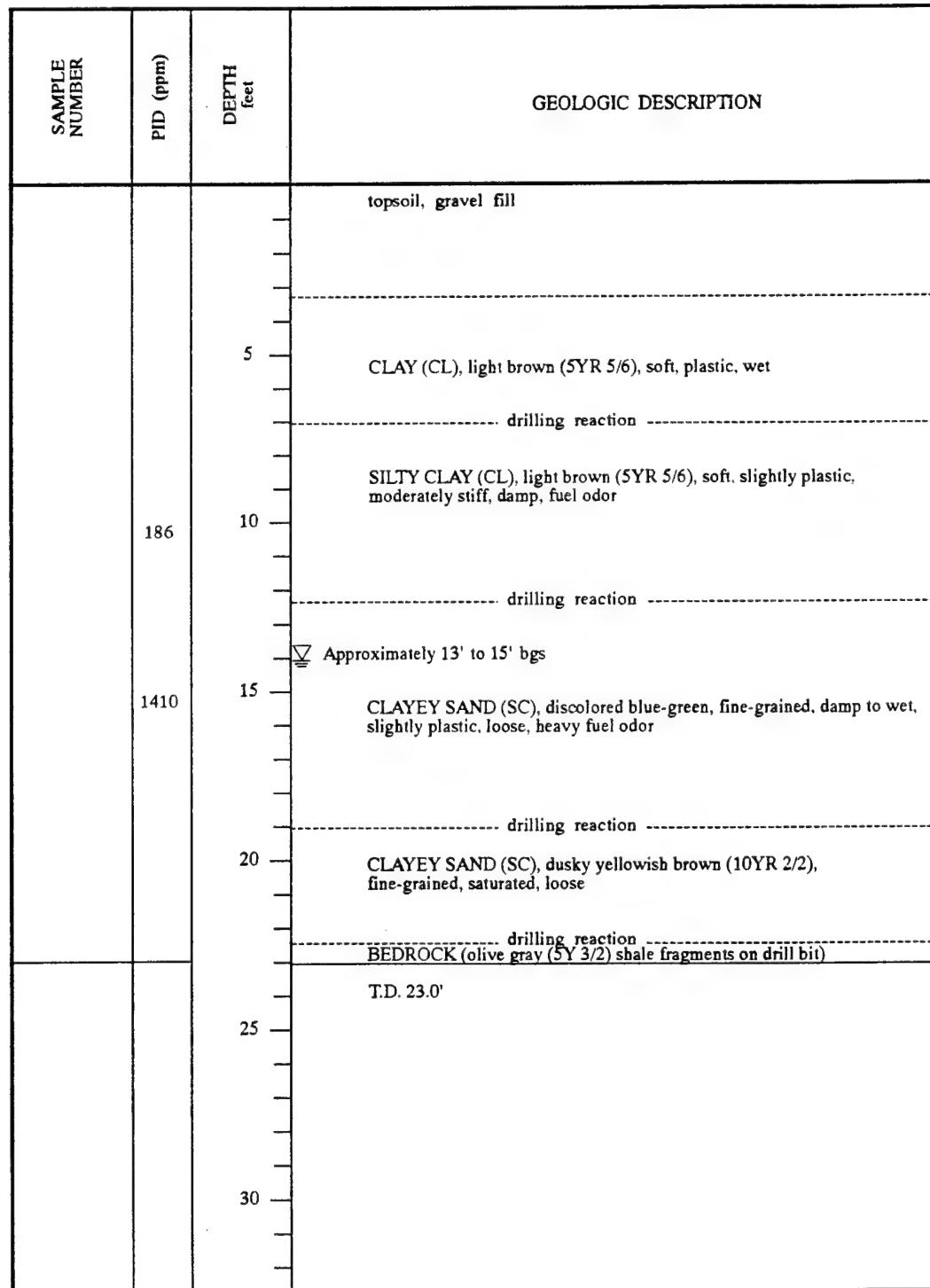
NR - Not Recorded

□ - Drive or continuous core sample.

MW214

BORING NUMBER: EW1

PROJECT NUMBER:	723097	PROJECT NAME:	Travis AFB NSGS
CLIENT:	AFCEE	DRILLER:	Gregg Drilling, Inc.
LOCATION:	IRPIMS Site 22 North and South Gas Stations	DRILLING METHOD:	Hollow-stem Auger
GEOLOGIST:	H. Pietropaoli	HOLE DIAMETER:	6.5 (enlarged to 14.5) inches
COMPLETION DATE:	12/21/94	TOTAL DEPTH:	23.0 feet below ground surface



▽ - First encountered groundwater.
---- - Contact approximately located.

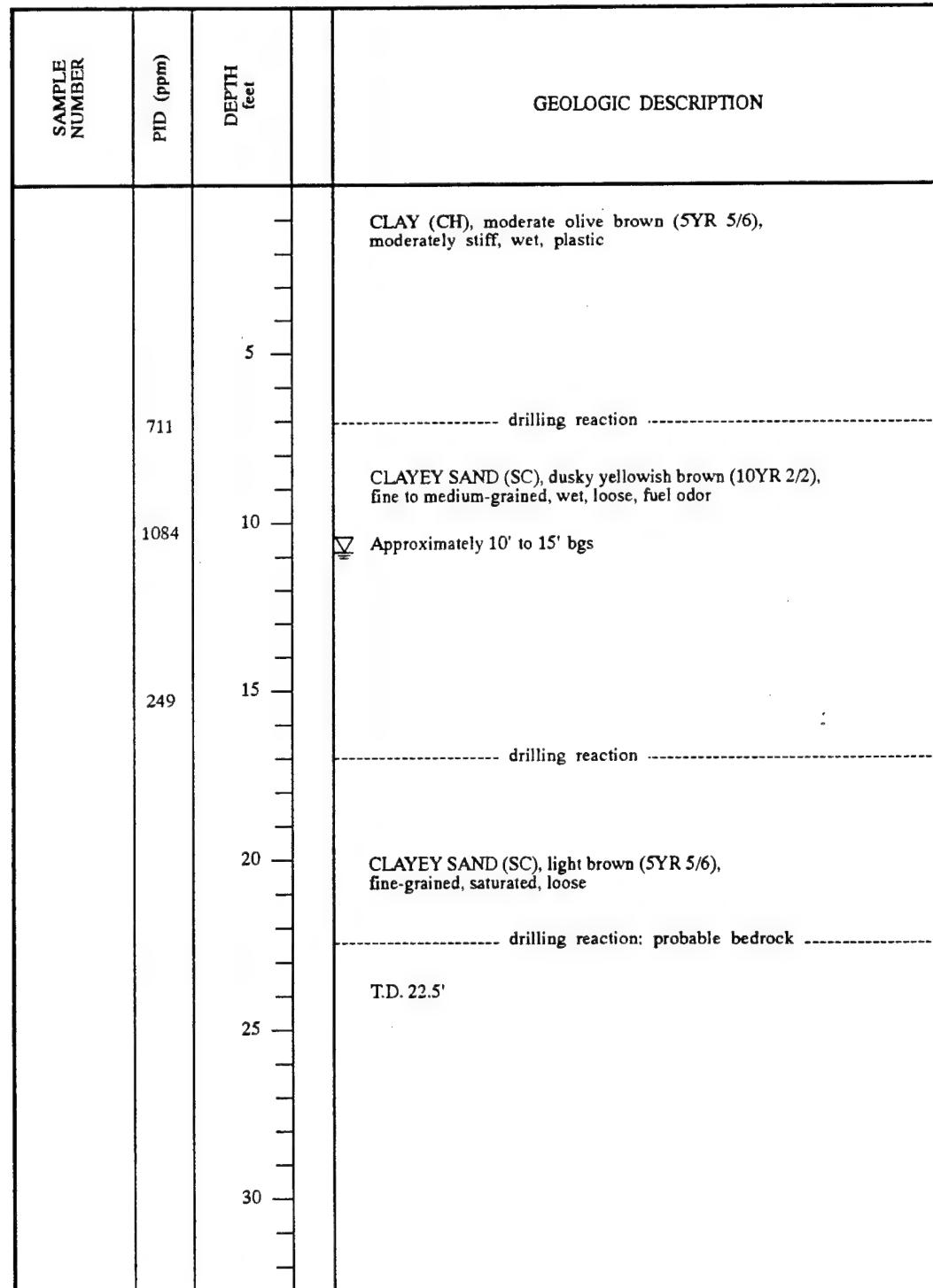
Lithology described from drill cuttings.

NR - Not Recorded

ns gew1

BORING NUMBER: EW2

PROJECT NUMBER:	723097	PROJECT NAME:	Travis AFB NSGS
CLIENT:	AFCEE	DRILLER:	Gregg Drilling, Inc.
LOCATION:	IRPIMS Site 22 North and South Gas Stations	DRILLING METHOD:	Hollow-stem Auger
GEOLOGIST:	H. Pietropaoli	HOLE DIAMETER:	6.5 (enlarged to 14.5) inches
COMPLETION DATE:	12/21/94	TOTAL DEPTH:	22.5 feet below ground surface



▽ - First encountered groundwater.

Lithology described from drill cuttings.

--- - Contact approximately located.

NR - Not Recorded

APPENDIX D

**PRELIMINARY EVALUATION OF INTRINSIC
REMEDIATION EVALUATION
FROM PREVIOUS INVESTIGATION**

(excerpted from Parsons ES, 1995)

4.0 PRELIMINARY EVALUATION OF INTRINSIC BIOREMEDIATION

4.1 INTRODUCTION

The purpose of this section is to present the results of a limited field investigation that was conducted to determine the potential for intrinsic bioremediation at the NSGS site. This investigation was conducted during the Stage 2 groundwater sampling event in December 1994 and January 1995. Because the field investigation was limited in scope, only a preliminary evaluation of the potential for intrinsic bioremediation is presented. Groundwater modeling was not performed.

Intrinsic remediation is an innovative remedial technology that relies on natural attenuation to remediate contaminants dissolved in groundwater. Mechanisms of natural attenuation of benzene, toluene, ethylbenzene, and xylene (BTEX) include advection, dispersion, dilution, sorption, volatilization, and biodegradation. Of these processes, biodegradation is the most important mechanism working to transform contaminants into innocuous byproducts. Intrinsic bioremediation occurs when indigenous microorganisms work to bring about a reduction in the total mass of contamination in the subsurface without the addition of nutrients. A technical protocol document has been prepared for AFCEE which presents protocols for data collection, groundwater modeling, and data evaluation in support of intrinsic remediation at petroleum contaminated sites (Wiedemeier *et al.* 1995). This document was used as the primary reference for field work conducted at the NSGS.

Microorganisms obtain energy for cell production and maintenance by facilitating the transfer of electrons from electron donors to electron acceptors, resulting in the oxidation of the electron donor and the reduction of the electron acceptor. Electron donors at this site are fuel hydrocarbon compounds and natural organic carbon. Fuel hydrocarbons are completely degraded or detoxified if they are utilized as the primary electron donor for microbial metabolism (Bouwer 1992). Electron acceptors are elements or compounds that occur in relatively oxidized states and include oxygen, nitrate, ferrous iron, sulfate, and carbon dioxide. Microorganisms preferentially utilize electron acceptors while metabolizing fuel hydrocarbons (Bouwer 1992).

Dissolved oxygen (D.O.) is utilized first as the prime electron acceptor. After D.O. is consumed, anaerobic microorganisms use electron acceptors in the following order of preference: nitrate, ferrous iron, sulfate, and carbon dioxide. Anaerobic destruction of the BTEX compounds is associated with the accumulation of fatty acids, production of methane, solubilization of iron, and reduction of nitrate and sulfate (Cozzarelli *et al.* 1990, Wilson *et al.* 1990).

4.2 FIELD ACTIVITIES

Field activities described in this report were primarily conducted during the Stage 2 groundwater sampling event between 27 December 1994 and 3 January 1995. However, some laboratory results are presented from the groundwater sampling event conducted in July 1994.

In addition to temperature, electrical conductivity, and pH, the following groundwater parameters were measured in the field:

- Dissolved oxygen (D.O.) by method E360.1 - direct reading instrument (a YSI model 51B was used)
- Oxidation/reduction potential (redox) by method A2580B - direct reading instrument (an Orion 250A with platinum redox electrode 96-78 and 900011 filling solution was used)
- Ferrous iron by method A3500-FeD - field analysis kit (HACH® 8146 was used)
- Alkalinity by method A2320B - field analysis kit (HACH® 8221 was used)

Dissolved oxygen (D.O.), redox potential, temperature, and pH measurements were taken immediately following well purging and prior to sampling. Aeration of samples, which can affect D.O., ferrous iron, and redox potential results, was minimized by using the field techniques described in Section 2.3.2.2.1 of the technical protocol document. Redox potential is reported relative to hydrogen (E_h) by using the appropriate potential developed by the platinum redox electrode at the measured temperature.

Samples taken for ferrous iron (Fe^{2+}) measurements were analyzed immediately following well purging and sampling. Samples taken for alkalinity measurements were analyzed within 24 hours of sampling. Nitrate-nitrogen, nitrite-nitrogen, and sulfate samples were analyzed by a fixed-base laboratory. A more detailed description of the field work can be found in Section 2.

4.3 LABORATORY ANALYSES

Results of analyses for total petroleum hydrocarbons as gasoline (TPHg); benzene, toluene, ethylbenzene, and total xylenes (BTEX); nitrate-nitrogen; nitrite-nitrogen; and sulfate in groundwater are shown in Table 4.1. Concentration contours of TPHg and benzene are shown on Figures 3.2 and 3.3.

4.4 DATA EVALUATION

4.4.1 Dissolved Oxygen

The D.O. concentrations in groundwater measured at the site in December 1994 and January 1995 are shown in Table 4.1. Figure 4.1 is an isopleth map showing the D.O. distribution in groundwater. Although this figure includes data collected from a limited number of

Table 4.1
Intrinsic Bioremediation Results In Groundwater
North and South Gas Stations, Travis AFB, California

Location	Laboratory Analyses ¹					Field Analyses ²					
	TPH-g (μ g/L)	BTEX (μ g/L)	Nitrate-Nitrogen (mg/L)	Nitrite-Nitrogen (mg/L)	Sulfate (mg/L)	Dissolved Oxygen (mg/L)	E_h (redox) (mV)	Ferrous Iron (mg/L)	Alkalinity (mg/L)	Temp. (° F)	pH (units)
MW136	630	51			180	0.1	226	2.61	600	19.2	6.45
MW140	580	3.7	3.7	NA	1,300	NA	NA	NA	NA	NA	6.98
MW141	31,000	27,830			275	0.1	133	3.16	1,400	19.5	7.03
MW201	1,180	13		NA	5,800	NA	NA	NA	NA	NA	6.84
MW202			1.9		4,770	0.1	171	0.19	340	18.0	6.40
MW206	11,800	50,500			13.6	0.1	161	5.32	480	19.0	7.07
MW208			11.2		206	1.3	413	0.17	340	18.5	6.76
MW209	250	29		NA	450	NA	NA	NA	NA	NA	6.82
MW210	19,900	6,580			754	0.2	202	6.42	620	20.5	6.45
MW211	2,190	447	3.0		2,330	0.7	387	0.22	640	17.5	6.37
MW212		NA	3.3		1,830	0.8	357	0.13	480	19.0	7.04
MW213			2.1		1,140	3.1	379	0.02	200	18.0	6.38
MW214			3.7		1,320	2.0	359	0.40	360	17.6	7.19

Notes:

¹ Laboratory analyses conducted during July 1994 field event except for MW-211, MW-212, MW-213, MW-214, which were conducted in December 1994/January 1995.

² Field analyses for D.O., E_h , ferrous iron, and alkalinity conducted during December 1994/January 1995 field event

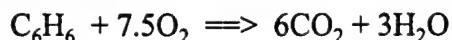
E_h = Oxidation - Reduction Potential relative to hydrogen.

Not Detected

NA : Not Analyzed

monitoring wells, comparison of Figures 3.2 and 3.3 with Figure 4.1 shows graphically that areas with elevated TPHg and benzene concentrations have depleted D.O. concentrations. This is a strong indication that aerobic biodegradation of the BTEX compounds is occurring at the site.

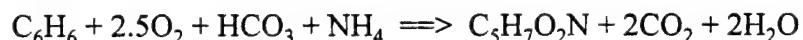
In the absence of microbial cell production, the oxidation (biodegradation) of benzene to carbon dioxide and water is given by:



Therefore, in the absence of microbial cell production, 3.1 mg of oxygen are required to completely mineralize 1.0 mg of benzene. Similar calculations can be completed for toluene (3.1 mg oxygen to 1.0 mg toluene), ethylbenzene (3.2 mg oxygen to 1.0 mg ethylbenzene), and total xylenes (3.2 mg oxygen to 1.0 mg xylene). The average mass ratio of oxygen consumed to total BTEX degraded is 3.1:1; therefore, approximately 0.32 mg of BTEX is mineralized to carbon dioxide and water for every 1.0 mg of D.O. consumed.

Assuming a background D.O. concentration of approximately 3.1 mg/L, the shallow groundwater at this site has the capacity to assimilate 0.99 mg/L (990 μ g/L) of total BTEX. This is a very conservative estimate of the assimilative capacity of D.O. because microbial cell mass production is not taken into account by the stoichiometry shown above.

When cell mass production is accounted for, the mineralization of benzene to carbon dioxide and water is given by:

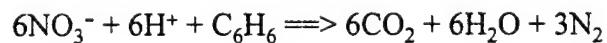


When cell mass production is accounted for, 1.03 mg of oxygen are required to mineralize 1.0 mg of benzene. Similar calculations can be made for toluene, ethylbenzene, and total xylenes. Approximately 0.97 mg of BTEX is mineralized to carbon dioxide and water for every 1.0 mg of D.O. consumed. With a background D.O. concentration of approximately 3.1 mg/L, the shallow groundwater at this site has the capacity to assimilate approximately 3.0 mg/L (3,000 μ g/L) of total BTEX if microbial cell mass production is taken into account.

4.4.2 Nitrate/Nitrite

Nitrate/nitrite (as nitrogen) concentrations in groundwater measured at the site in July 1994 and December 1994/January 1995 are shown in Table 4.1. Figure 4.2 is an isopleth map showing the nitrate-nitrogen distribution in groundwater. Comparison of Figures 3.2 and 3.3 with Figure 4.2 shows graphically that areas with elevated TPHg and benzene concentrations have depleted nitrate concentrations. These relationships provide strong evidence that anaerobic biodegradation of the BTEX compounds is occurring at the site through the microbially mediated process of denitrification.

In the absence of microbial cell production, the biodegradation of benzene to carbon dioxide and water is given by:



Therefore, in the absence of microbial cell production, 4.8 mg of nitrate are required to completely mineralize 1.0 mg of benzene. Similar calculations can be completed for toluene (4.9 mg nitrate to 1.0 mg toluene), ethylbenzene (4.9 mg nitrate to 1.0 mg ethylbenzene), and total xylenes (4.9 mg nitrate to 1.0 mg xylene). The average mass ratio of nitrate consumed to total BTEX degraded is 4.9:1; therefore, approximately 0.21 mg of BTEX is mineralized for every 1.0 mg of nitrate consumed.

Assuming a background nitrate concentration of 11.2 mg/L (the concentration measured at MW-208), the shallow groundwater at this site has the capacity to assimilate 2.35 mg/L (2,350 μ g/L) of total BTEX during denitrification. This is a very conservative estimate of the assimilative capacity of nitrate because microbial cell mass production has not been taken into account by the stoichiometry shown above.

4.4.3 Sulfate

Sulfate concentrations in groundwater measured at the site in July 1994 and December 1994/January 1995 are shown in Table 4.1. The sulfate concentrations ranged from 4,770 mg/L and 5,800 mg/L at the north end of the site (background) to less than 300 mg/L in the SGS contaminated source area. Most groundwater samples with elevated TPHg and benzene concentrations also had low sulfate concentrations, particularly where D.O. was also depleted.

Depleted sulfate concentrations may be the result of anaerobic biodegradation of the BTEX compounds through the microbially mediated process of sulfate reduction. Sulfate reduction results in the production of sulfide, which was not included for analysis in this limited field investigation. Because some groundwater samples which had undetectable or low TPHg and benzene concentrations also had low sulfate concentrations and because sulfide concentration was not analyzed, it cannot be determined definitively at this time whether sulfate reduction is occurring at the site. However, the general pattern of sulfate concentrations relative to BTEX concentrations suggests that sulfate reduction is occurring. Because sulfate concentrations in the site groundwater are relatively high, sulfate reduction is likely an important process contributing to the natural attenuation of petroleum hydrocarbons.

In the absence of microbial cell production, the biodegradation of benzene by sulfate reduction is given by:



Therefore, in the absence of microbial cell production, 4.6 mg of sulfate are required to completely mineralize 1.0 mg of benzene. Similar calculations can be completed for toluene (4.7 mg sulfate to 1.0 mg toluene), ethylbenzene (4.8 mg sulfate to 1.0 mg ethylbenzene), and xylene (4.8 mg sulfate to 1.0 mg xylene). The average mass ratio of sulfate to total BTEX is thus 4.7:1; therefore, approximately 0.21 mg of BTEX is mineralized for every 1.0 mg of sulfate consumed.

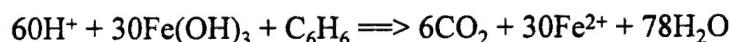
The highest sulfate concentrations, 4,770 mg/L and 5,800 mg/L, were found in the two northernmost wells. Assuming that these wells represent a background sulfate concentration

of about 5,000 mg/L, the site groundwater has the capacity to assimilate 1,050 mg/L (1,050,000 $\mu\text{g/L}$) of total BTEX due to sulfate reduction.

4.4.4 Ferrous Iron

Ferrous iron concentrations in groundwater measured at the site in December 1994 and January 1995 are shown in Table 4.1. In general, groundwater samples with elevated TPHg and benzene concentrations, depleted D.O., and low levels of nitrate-nitrogen and sulfate also had elevated concentrations of ferrous iron. These results suggest that ferric iron is being reduced to ferrous iron during biodegradation of BTEX compounds.

In the absence of microbial cell production, the biodegradation of benzene by ferric iron reduction is given by:



Therefore, in the absence of microbial cell production, 41.1 mg of Fe(OH)_3 are required to completely mineralize 1.0 mg of benzene. This results in a mass ratio of ferrous iron (Fe^{2+}) produced to benzene degraded of 21.5:1. Similar calculations can be completed for toluene (21.9 mg of Fe^{2+} produced during biodegradation of 1.0 mg of toluene), ethylbenzene (22.0 mg of Fe^{2+} produced during biodegradation of 1.0 mg of ethylbenzene), and xylene (22.0 mg of Fe^{2+} produced during biodegradation of 1.0 mg of xylene). The average mass ratio of Fe^{2+} produced during total BTEX biodegradation is thus 21.8:1; therefore, approximately 1.0 mg of BTEX is mineralized for every 21.8 mg of Fe^{2+} produced.

The highest measured Fe^{2+} concentration at the site was 6.42 mg/L. This suggests that the shallow groundwater at this site has the capacity to assimilate 0.30 mg/L (300 $\mu\text{g/L}$) of total BTEX during iron reduction. This is a very conservative estimate of the assimilative capacity of iron because microbial cell mass production has not been taken into account by the stoichiometry shown above. In addition, this calculation is based on observed ferrous iron concentrations and not on the amount of ferric hydroxide available in the aquifer. Therefore, iron assimilative capacity could be much higher.

Recent evidence suggests that the reduction of ferric iron to ferrous iron cannot proceed at all without microbial mediation (Lovley and Phillips, 1988; Chapelle, 1993). None of the common organic compounds found in low-temperature, neutral, reducing ground water could reduce ferric oxyhydroxides to ferrous iron under sterile laboratory conditions (Lovley *et al.*, 1991). This means that the reduction of ferric iron requires microbial mediation by microorganisms with the appropriate enzymatic capabilities. Because the reduction of ferric iron cannot proceed without microbial intervention, the elevated concentrations of ferrous iron that were measured in the contaminated groundwater at the site are very strong indicators of microbial activity.

4.4.5 Oxidation/Reduction Potential

The oxidation/reduction (redox) potentials of groundwater measured at the site in December 1994 and January 1995 are shown in Table 4.1. Redox potential (E_h) is a measure of the relative tendency of a solution to accept or transfer electrons. The redox potential of a

groundwater system depends on which electron acceptor is being reduced by microbes during BTEX oxidation. The redox potential, measured relative to hydrogen, at this site ranged from 161 millivolts (mV) to 413 mV.

Figure 4.3 is an isopleth map showing the redox potential distribution in groundwater. Although this figure includes data collected from a limited number of monitoring wells, comparison of Figures 3.2, 3.3, and 4.1 with Figure 4.3 shows graphically that areas with elevated TPHg and benzene concentrations and depleted D.O. have lower redox potential. In addition, areas at the site with low redox potentials generally coincide with areas of low nitrate and sulfate concentrations and elevated ferrous iron concentrations (see Table 4.1). These results suggest that dissolved BTEX at the site is subjected to a variety of biodegradation processes including aerobic respiration and anaerobic denitrification, iron reduction, and sulfanogenesis.

4.4.6 Alkalinity

The total alkalinity (as CaCO_3) of site groundwater measured in December 1994/January 1995 is shown in Table 4.1. Alkalinity is a measure of a groundwater's ability to buffer changes in pH caused by the addition of biologically generated acids. Total alkalinity at the site is relatively high and varies from 200 mg/L to 1,400 mg/L. This amount of alkalinity should be sufficient to buffer potential changes in pH caused by biologically mediated BTEX oxidation reactions.

4.4.7 pH

The pH of groundwater measured at the site in July 1994 and December 1994/January 1995 is shown in Table 4.1. The pH of a solution is the negative logarithm of the hydrogen ion concentration $[\text{H}^+]$. The pH of groundwater at the site ranges from slightly acidic (6.3) to neutral (7.2). Most pH measurements were between 6.8 and 7.1, which is optimal for BTEX-degrading microbes.

4.4.8 Temperature

The temperature of groundwater measured at the site in July 1994 and December 1994 and January 1995 is shown in Table 4.1. Temperature affects the types and growth rates of bacteria that can be supported in the groundwater environment. Temperatures in the shallow saturated zone varied from 17.5°C to 20.5°C. These are moderate temperatures for groundwater, suggesting that bacterial growth should not be inhibited.

4.4.9 Assimilative Capacity

The data presented in the preceding sections suggest that mineralization of BTEX compounds is occurring through the microbially mediated processes of aerobic respiration, denitrification, and possibly iron reduction and sulfate reduction. Based on the stoichiometry presented in preceding sections, the BTEX assimilative capacity of groundwater at the site is at least 1,054,000 $\mu\text{g/L}$ (Table 4.2).

TABLE 4.2
Expressed Assimilative Capacity of Site Groundwater

**North and South Gas Stations
Travis Air Force Base, California**

Electron Acceptor or Process	BTEX Assimilative Capacity (µg/L)
Dissolved Oxygen	990
Iron Reduction	300
Nitrate	2,350
Sulfate	1,050,000
Expressed Assimilative Capacity	1,053,640
Highest Observed Total BTEX Concentration	103,060

The calculations presented in earlier sections are very conservative because they do not account for microbial cell mass production. In addition, the measured concentrations of ferrous iron may not be the maximum achievable. The highest dissolved-phase total BTEX concentration observed at the site was 103,060 µg/L in monitoring well MW-138 in July 1994 (see Table 3.4). However, the total BTEX concentration in groundwater across most of the site is less than 10,000 µg/L, as indicated on Figures 3.2 and 3.3.

4.5 CONCLUSIONS

On the basis of the calculations presented in the preceding sections and on site observations, groundwater at the site has significant assimilative capacity to degrade dissolved-phase BTEX contamination. Even the highest observed BTEX concentrations observed at monitoring wells MW-135 and MW-138 (Figure 3.3), which exhibited free product, are significantly lower than the expressed assimilative capacity of the groundwater.

Conservative assumptions were used in the assimilative capacity calculations. In addition, other anaerobic biodegradation processes may be occurring which were either not measured or the data was inconclusive (e.g., methanogenesis). Therefore, the groundwater may have a high assimilative capacity and may be capable of intrinsically remediating the areas of lower BTEX concentration, particularly if the areas of higher BTEX concentrations were treated by source removal actions (e.g., groundwater extraction or bioventing).

More information is needed to fully evaluate intrinsic bioremediation at the site, including the following:

- Measurements of D.O., redox potential, nitrate, nitrite, sulfate, ferrous iron, and alkalinity at a much larger number of the existing monitoring wells, including at least one background well. This data would improve the conceptual site model and provide additional qualitative and quantitative evidence of biodegradation patterns and assimilative capacity.

- Measurement of sulfide and methane concentrations in groundwater to verify that sulfate reduction and/or methanogenesis are occurring at the site.
- Groundwater modeling using Bioplume II, including various scenarios for groundwater cleanup at extraction wells EW-1 and EW-2 (see Figures 3.2 and 3.3). Modeling data could be used to predict the ultimate fate of the contaminant plume and estimate the time required for cleanup.